Indoor Positioning and Monitoring System Using Smartphone and WLAN (IPMS)

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ABSTRACT

Buildings such as malls, offices, airports and hospitals nowadays have become very complicated which increases the need for a solution that helps people to find their locations in these buildings. GPS or cell signals are commonly used for positioning in an outdoor environment and are not accurate in indoor environment. Smartphones are becoming a common presence in our daily life, also the existing infrastructure, the Wi-Fi access points, which is commonly available in most buildings, has motivated this work to build hybrid mechanism that combines the APs fingerprint together with smartphone barometer sensor readings, to accurately determine the user position inside building floor relative to well-known landmarks in the floor. Also the proposed system offers a monitoring activity which lets the administrator to watch and locate certain user inside the building.The system is tested in a big building indoor environment and achieved positioning accuracies of approximately 2.1 meters.

Key words: Indoor Positioning System, Indoor Localization System, Indoor Monitoring System, Smart Phones, fingerprinting, Barometer sensor, WLAN, IPMS.

نظام مراقبه وتحديد موقع الشخص داخل البنايه باستخدام الهاتف الذكي وشبكه لاسلكيه محليه

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الخلاصة

اصبحت المباني مثل مراكز التسوق والمكاتب والمطارات والمستشفيات في الوقت الحاضر معقده للغايه ممايزيد الحاجه الى وجود حل يساعد الناس في ايجاد موقعهم في هذه المباني. ويعد نظام تحديد المواقع العالمي واشاره ابراج الاتصالات احدى الطرق الشائعه في تحديد مواقع الاشخاص خارج تلك المباني ولكنها ليست دقيقه في تحديد مواقع الاشخاص داخل المباني. ان وجود الهواتف الذكيه في حياتنا اليوميه بصوره شائعه وكذلك توفر البنيه التحتيه القائمه على وجود نقاط الوصول قد حفز على بناء نظام هجين يجمع بصمه نقاط الوصول مع قراءات جهاز الاستشعارفي الهاتف الذكي لتحديد موقع الشخص بدقه على الطابق نسبه الى علامه معروفه في هذا الطابق. ايضا النظام المقترح يوفر خاصيه المراقبه التي تسمح للمشرف بمشاهده وايجاد موقع شخص معين داخل البنايه. وقد تم اختبار النظام في بنايه كبيره حيث بلغت نسبه الدقه في تحديد موقع الشخص مايقارب 2,1 متر.

1. INTRODUCTION

Indoor positioning system recently has become an important topic in the research area due to the growing demand for location aware systems that filter information based on the location of the current smartphone. Many approaches, mechanisms, have been suggested and built for efficient and accurate indoor positioning system. However, each of which comes with its merits and demerits. GPS is the most widely used satellite based positioning system, which offers maximum coverage. GPS cannot be deployed inside buildings, because it requires line-of-sight transmission between receivers and satellites which is not possible in indoor environment due to the obstacles inside the buildings, **Hightower,** and **Borriello**, **2001. Balas, 2011.** presents a crowdsourcing-based localization system for estimating the positions of the devices through using smartphone sensor and Wi-Fi readings. However, the accuracy of this approach is approximately 7m which decreases the performance of the system, furthermore, as mentioned in **Balas, 2011.** the number of training data points has to be high in order to have a small error and people might not provide this data whenever they are asked to by the phone. Most probably, the users will provide data while in their offices or in the common areas and not while they are walking down the hallways. **Li, 2012.** presents an indoor positioning system using smartphone sensors; this system interacts with a user to get the initial location through user input, and provides the current position estimate on an indoor map. However, smartphone sensor suffers from noises which makes reliable step detection hard task, the random bouncing of mobile phones, caused by putting phone in a pocket, switching from left to right hand, operating on touch screen, or taking a phone call, can generate false positives in the detection; The step length of a person's walking can vary quite a lot over time, due to speed, terrain, and other environmental constraints. Furthermore, it is well understood that people with different physical profiles such as height, weight, sex, or walking style have different step length. In order to eliminate the challenges as mentioned above, additional overhead and complexity are presented in the implementation algorithm. **Kothari, et al., 2012.** present an indoor positioning system based on Wi-Fi Access Points incorporated with smartphone sensor. However, it needs a pioneer robot equipped with a SICK LM200 laser rangefinder for collecting signals from the APs during the process of APs detection which means an additional hardware is needed results in increasing the complexity of implementation as well as increasing the cost. **Aboodi, and Wan, 2012.** present an indoor positioning system based on RSS fingerprint in conjunction with trilateration technique. However, using trilateration technique imposes a constraint on the floor's infrastructure because each floor should contain at least three APs. Also, it uses LSE (Least Square Estimation), Min-Max and Kalman filter algorithms which increases the complexity of the implementation as well as increasing in the response time.

The rest of the paper is organized as follows. Section 2 describes in details the proposed system mechanism. Section 3 describes the performance evaluation of the proposed system and provides a comparison of indoor positioning techniques based on their accuracies. Finally, section 4 concludes the paper.

2. PROPOSED SYSTEM

This section logically illustrates the mechanism of the proposed system structure together with each module that constructs the overall system architecture. The proposed system consists of two phases; the training phase which is used to collect the strongest signal strength, of each AP, in each floor in the building to be sent and stored in the database server. The localization phase is used to retrieve the strongest signal strength from the database server then in conjunction with current smartphone readings of AP signal strength and smartphone barometer are used to determine user position.

2.1 Training Phase

Fig. 1 shows the main components used in the training phase. The main function of the training phase is to collect and record RSS of every AP, Pressure and height for each floor inside the site. In this work the system is planned to work on a site which consists of a number of buildings each building consists of a number of floors. Also each floor, which has its own pressure and height, is equipped with one or more APs. Hence, each AP is identified by: site name, building name, floor number, AP name, received signal strength (RSS), and AP MAC address. Before the training phase starts, the system administrator smartphone is loaded with a utility that is responsible for collecting the above mentioned information and then sent to be stored in the database server. Later In the localization phase, these information in conjunction with information collected in real time, are used to determine the local position of user. The steps that are involved in the training phase are listed below:

1) The training phase utility is loaded in the system administrator smart phone and it is used only during the training phase by the system administrator.
2) The site name is entered manually by the system administrator smartphone and sent to be stored in the database server.
3) For each building, the system administrator walk through, the name of the building is entered manually and sent to be stored in the database server.
4) For each floor, of each building, the floor number is entered manually and sent to be stored in the database server.
5) Now for each floor while the administrator is walking through, the utility of the administrator smartphone detects each AP and continuously read signal strength of each AP, as each AP is recognized by its MAC address. When reaching to the end of the certain floor, the number of recorded RSS for each AP is minimized at the Smartphone to the one of the strongest RSS recorded for each AP; then, the strongest RSS of each AP is sent to be stored in database server. Also, a well-known landmark such as common room in the floor, associated with each AP, is also sent to be recorded in the database server. Note, the landmark should not be far away from the AP more than one meter.
6) In addition, the utility of the administrator smartphone also detects the pressure, which is used to calculate the height value, for each floor and send the height to be stored at the database server. Note that, each floor has its own pressure and height values that are different from other floors. The purpose of storing the height value, for each floor, will be explained and analysed in the localization phase, section (2.2).

Fig. 2 shows the flowchart of the training phase for a building. **Fig. 3** shows the Database entries.

2.2 Localization Phase

Fig. 4 shows the main components used in the localization phase. This phase constitutes the main objective of this paper which is responsible for providing "**Locate Me"** service, this phase determines and notifies the user (through her/his smartphone) about her/his position relative to well-known landmark inside the building. Also, it provides **"Monitoring"** service which lets the administrator to locate certain users inside the building. Before discussing and analyzing the technique and the approach used in this phase, it is found necessary to list the steps that would clear the operation of different interoperated components:

A. Locate Me Service

1) While the user is walking inside the building, the **"Locate Me"** utility, embedded in the smartphone, detects and reads the Wi-Fi RSS of the APs, pressure (for height calculations) for the current floor and then compare them with retrieved RSS and height (which are stored in the server during training phase), remember that each AP, in the building, is recognized by site name, building name, floor number, AP's name, RSS and its MAC address. Then a mechanism called "Fingerprint Mechanism", explained later in section (2.3) is used to determine the closest AP (the one with strongest RSS) to the user and then it converts the strongest RSS to a distance that represents how far the user is from the AP (landmark). Note that, the purpose of extracting the height and pressure of each floor (using the smartphone Barometer sensor) is: it happens that the detected closest AP to the user is in another floor, actually not in the floor where the user exists. Hence the use of the pressure and height, which are unique for each floor, will determine in which floor the user exists.

2) A "Filter Scheme" mechanism, shown in **Fig. 4**, is used to purify and removing the noise that is associated with APs RSS and then determine the accurate and final position of the user to be displayed on the user smartphone. The "Filter Scheme" mechanism is explained in details later in section (2.5).

B. Monitoring Service

The monitoring service provides the administrator the capability of watching the users inside the building. This service mainly depends on the "**Locate Me**" service. Thus whenever the " **Locate Me**" service is activated then all the information regarding users position are periodically send and stored in the database server to be accessed by the administrator for the purpose of monitoring. This service is explained in section (2.4).

2.3 Fingerprint Mechanism

Finger print mechanism, is the process of storing information at the training phase to be retrieved at any time during the localization phase. It is important to know there are two types of indoor localization, vertical and horizontal indoor localizations, it is necessary to distinguish between them as follows:

1) Vertical localization which is the process of estimating user's location according to which floor number the user exists.

2) Horizontal localization which is the process of estimating user's location on the specific floor relative to well-known landmark at this floor.

2.3.1 Vertical Localization

A problem that exists with the Wi-Fi mechanism is the number of APs for a fingerprint can be changed because of the nature of radio waves. Especially inside buildings, external factors like moving object, open or closed doors, change the signal strengths of the APs. An AP that was measured during the training phase might not be received during the localization phase and vice versa. Therefore, to account for these changes in the environment, the proposed system depends mainly on the Barometer sensor of the smartphone in the vertical localization.

The proposed system uses Wi-Fi signal strength and the smartphone Barometer sensor to estimate vertical user's location, which floor number the user may exist. Barometer sensor is used to measure height (altitude) and pressure, note that pressure and height have different values in each floor in a specific building.

In the localization phase, the Wi-Fi signals of the APs are detected by the user's smartphone. Then the MAC addresses of the APs, from which the signals are received by the smartphone, are compared with MAC addresses of the retrieved AP signals (stored in the database server during the training phase). Furthermore, the Barometer sensor reading, associated with each detected AP, is retrieved from the database server to be compared with current Barometer sensor reading to determine which APs are in the floor where the user exists.

It is important to note, the Barometer sensor reading is changing with time, suppose the Barometer sensor has a height value equal to 150.5 m at 10 O'clock morning. This value will be altered according to the change in the parameters: pressure, temperature and humidity. Thus, the Barometer sensor will have different reading after an hour, changing in height may be increased or decreased according to the parameters mentioned above. This problem results in producing error when the localization phase occurs at time different from the time of the training phase.

The proposed system fixes this problem through storing the Barometer sensor reading at each floor in the database server, during training phase, arranged from the first floor to the last floor of a specific building. Now, during the localization phase, which must start at the first floor, the reading of the Barometer sensor at the first floor is subtracted from the value of the Barometer sensor of the first floor stored during training phase, the result represents the difference between the two values. This difference represents a new value called "Reference Point", the new value added to the all Barometer sensor readings, of each floor, that are detected and stored at the database server during the training phase. For example, suppose a building consists of three floors:

Let $Height_{training1}$ = 150.5 at first floor, $Height_{training2}$ = 153 at second floor and $Height_{training3}$= 157 at the third floor, if Barometer sensor reading has values equal to $Height_{localization1}$=164 at first floor, $Height_{localization2}$=167 at second floor and $Height_{localization3}$ = 170 at third floor. Then during the localization phase, the following equations are applied:

Reference Point=$Height_{localization1}$ - $Height_{training1}$ (1)

=164-150.5=13.5

$Height_{localization\ new1}$=$Height_{localization1}$ - *Reference Point* (2)

=164-13.5= 150.5 which is exactly 150.5, the training phase value of the first floor.

$Height_{localization\ new2}$=$Height_{localization2}$-*Reference Point* (3)

= 167-13.5=153.5 which is approximate to 153, the training phase value of the second floor.

$Height_{localization\ new3}$=$Height_{localization3}$-*Reference Point* (4)

= 170-13.5=156.5 which is approximate to 157, the training phase value of the third floor.

The above new Height Barometer localization values are stored in a temporary list, inside the smartphone, and updated continuously while the user is moving inside the building. Actually, the list is updated every 5 seconds, according to the above mentioned procedure, to eliminate the problem of Barometer sensor readings variations in different times of the day. Actually, In other words every 5 seconds a new Reference Point is calculated and the above mentioned equations are applied again.

2.3.2 Horizontal Localization

It is time now to determine the horizontal localization, suppose the following scenario:

After performing the training phase for the first floor, suppose there are four APs called A, B, C, D and each one has its own RSS value; these values are listed in **Table 1**.
During the localization phase, the detected APs and their own RSS are listed in **Table 2** which illustrates that the user is closest to AP B which has strongest RSS. Now, to find the closest AP to the user, the Euclidean distance rule shown in Eq. (5) is applied.

$$D=\sqrt{(RSS_{tr}-RSS_{lo})^2} \quad (5)$$

Where D represents Euclidean distance; RSS_{tr} represents received signal strength at training phase; RSS_{lo} represents received signal strength at localization phase.

Note that, the standard form of the Euclidean equation as used in previous works, **Navarro, et al., 2011.** and **Grossmann, et al., 2008.** includes summation symbol inside the square root see Eq. (6):

$$D=\sqrt{\sum_{i=1}^{N}(RSS_{tr}-RSS_{lo})^2} \quad (6)$$

Where D represents Euclidean distance; RSS_{tr} represents received signal strength at training phase; RSS_{lo} represents received signal strength at localization phase; N is the number of the APs. Actually, Eq. (6) is used in the environment where group of APs are collected together to represent certain well-known landmark at the floor. This approach is prone to error due to

the fact, suppose each floor has a number of APs which are collected in four groups. During positioning time the APs are detected in more than one group, as long as each group has a specific well-known landmark, then in order to estimate the closest well-known landmark, Eq. (6) is calculated for each group.
Therefore, the summation symbol is used in the process of calculation for each group; the group which has the smallest D has the closet position to the well-known landmark. However, whenever the number of matching APs is increased then D will be increased producing erroneous and inaccurate results.

In our proposal, the idea of APs groups is not adopted, during the localization phase all the APs of certain floor are detected and compared with corresponding retrieved APs. Therefore, the Euclidean equation is modified through eliminating the summation symbol from the equation. Hence the modified Euclidean equation is applied for the example of **Table 2** as follows:

D1=$\sqrt{(-50-(-60))^2}$ = 10

D2=$\sqrt{(-55-(-50))^2}$ = 5

D3=$\sqrt{(-50-(-70))^2}$ =20

D4=$\sqrt{(-45-(-85))^2}$ =40

It is clear that the smallest distance is D2 which means the user is closest to AP B. In order to calculate the distance in meter that how far the user is from AP B, Eq. (7) is used.

$$D_{meter} = 3 * 10^{(\frac{RSS}{110})} \quad (7)$$

D_{meter} = $3 * 10^{(50/110)}$= 8m

WhereD_{meter}, is the real distance that the user is far away from the well-known landmark. Note, referring to**, Park, 2007. Adchi,** and **LitePoint, 2014.** most of the APs have a maximum indoor range of 30m. Referring to **Galias, et al., 2013.** the minimum RSS level received by smartphone is -110db. Therefore, Eq. (7) has a maximum range of 30m. **Fig. 5** shows the flowchart of the localization phase, **“Locate Me”** service.

2.4 Monitoring Service

As mentioned in section (2.2), the localization phase offers **“Monitoring”** service for the administrator to locate users inside the building. Actually, as long as the user position is determined in **“Locate Me”** service, explained in section (2.3), then the “**Monitoring**” service is smoothly accomplished according to the following steps:

1) As soon as activating the system by the user, the IPMS starts the process of finding user position relative to the well-known land mark as explained in details in the “**Locate Me**” service. In other words, user smartphone starts the process of finding user position without user’s knowledge.

2) This information is associated with the username which is inserted by the user during the process of system's activation.
3) This information is uploaded to the database server.
4) The administrator can access the database server at any time and retrieve user position.

Note, the procedure of finding user's position is repeated every 3 seconds which results in updating user's position every 3 to 5 seconds in the database server.

2.5 Filter Scheme

Filter is used to purify the result of finding the closest AP based on Euclidean distance algorithm. The idea is to make the algorithm so that the impact of large differences in RSS is reduced, thus filter out the large differences so that if the RSS difference is larger than a certain threshold, **So, et al., 2013.** the distance measure is no longer increased. Referring to Eq. (4):

$$Let\ (RSS_{tr} - RSS_{lo}) = C \quad (8)$$

$$D = \sqrt{C^2} \quad (9)$$

$$C = (RSS_{tr} - RSS_{lo}) \qquad if \qquad |RSS_{tr} - RSS_{lo}| < TH \quad (10)$$

$$C = TH \qquad if \qquad |RSS_{tr} - RSS_{lo}| \geq TH \quad (11)$$

Where TH is the threshold value.

Now, in order to compensate the effect of some cases such as user orientation, user height, how the user holds the smartphone, etc. RSS is shifted inside a certain range, **So, et al., 2013.**

$$D = \sqrt{(C + z)^2} \quad (12)$$

Where z is the shift value.

According to **So, et al., 2013,** TH between range 10 to 30db and z in range between 3 to 10.

3. PERFORMANCE EVALUATION

This section demonstrates and illustrates the practical performance results that are obtained from applying the proposed system in real environment; **Al Mansour Mall** building which consists of four floors. The reason of applying the proposed system, in the above mentioned site, is to have a test in vital place in real life which is crowded with people.

3.1 User Positioning System Testing

The training phase of **Al Mansour Mall** building is conducted for the entire building floors. While the localization (positioning) phase is conducted in third and fourth floors, where five locations were taken for the test in the third floor and ten locations are tested in the fourth floor. **Tables 3** and **Table 4** show the results obtained from the test. From the results, the proposed system achieved accuracy of approximately an average of 2.1m.
This section presents the results of testing the system from user point of view, in other words if the user is lost inside the building it is simple to find her/his location using the positioning system. Also suppose two friends lost each other inside crowded Mall; in this case each one

can find her/his location and send a text message to the other, using the positioning system, to meet each other again.

3.2 User Monitoring System Testing

This section presents the results from the administrator point of view; in this test the user has changed his location five times. **Table 5** illustrates the location results recorded by the administrator smartphone.

Accuracy (or location error) of a system is the important user requirement of positioning systems. Accuracy can be reported as an error distance between the estimated location and the actual mobile location. Sometimes, accuracy is also called the area of uncertainty; that is, the higher the accuracy is, the better the system is. Some compromise between "suitable" accuracy and other characteristics is needed. **Table 6** shows system accuracies.

Note, the third system, shown in **Table 6**, achieves quite good accuracy of 2m which is nearly equal to our proposal that achieves accuracy of an average of 2.1m. Actually, because this system depends solely on the smartphone sensors suffers many challenges, some of them mentioned in section 1and the others in **Li, et al., 2012.** which degrade system performance in the long run of use.
The fifth system, shown in **Table 6**, also achieves quite good accuracy of 2.6m. But this system depends solely on the Wi-Fi signals and because it uses complex mechanism, as mentioned in section 1, which consumes a lot of computation time that results in slow response time to the user.

4. CONCLUSION

A hybrid indoor positioning and monitoring system is built that integrates smartphone sensors and Wi-Fi fingerprinting. The main advantage of this research is the creation of a system that achieves the benefits of the flexibility, offering good coverage, user friendly, reducing the complexity of the implementation as much as possible, having a reasonable cost and finally producing high accuracy. The proposed IPMS is suitable for use at any time; using public database server which makes the proposed system services available 24 hours a day. The proposed IPMS depends on the APs of the building which are in turn produce building level coverage. The proposed IPMS enhances the mechanism of using the well-known fingerprint algorithm, K-nearest neighbor, for dealing with Wi-Fi signals during the training and localization phases respectively. Furthermore, it enhances the Barometer sensor readings which fix the problem of Barometer sensor readings variation with time. Finally, the proposed IPMS is highly reasonable which provides good accuracy and consistent position information. It was tested into two vital buildings; the results showed the average of accuracy of the proposed IPMS is approximately 2.1m.
Actually, to achieve the above mentioned accuracy, each landmark has to be attached or adjoined to corresponding AP. In case there is no familiar landmark attached to AP, then it is possible to attach a simple landmark that illustrates the location of the AP relative well-known landmark in the building floor.

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Table 1. First Floor APs at Database Server.

AP_Name	RSS (db)
A	-50
B	-55
C	-50
D	-45

Table 2 First Floor APs Detected during Localization Phase.

AP_Name	RSS (db)
A	-60
B	-50
C	-70
D	-85

Table 3 Third Floor Results.

AP_Name	Well-known landmark	Real Distance (m)	Estimation Distance (m)	Accuracy (m)
Barcelona Cafe	**Barcelona Cafe**	**6**	**8.1**	**2.1**
Barcelona Café 1	**Barcelona Café**	**9**	**11**	**2**
Clarks	**Clarks**	**5**	**7**	**2**
Party 21	**Party**	**7**	**8.9**	**1.9**
Cosmetic	**Cosmetic**	**4**	**5.7**	**1.7**

Table 4 Fourth Floor Results.

AP_Name	Well-known landmark	Real Distance (m)	Estimation Distance (m)	Accuracy (m)
Tche Tche inside	Tche Tche inside	5	7.3	2.3
Tche Tche outside	Tche Tche outside	7	9.9	2.9
Carnval	Carnval	9	10.9	1.9
Carnval Cinema	Carnval Cinema	6	7.5	1.5
Super Star Restaurant	Super Star Restaurant	4	5.5	1.5
Iraqi Cinema	Iraqi Cinema	3	4.9	1.9
Chicken Cottage	Chicken Cottage	7	9	2
Jungle Land	Jungle Land	8	10	2
Mangel Plus	Mangel Plus	6.5	8	1.5
Kanafanje1	Kanafanje café	11	13.6	2.6

Table 5 Monitoring System Accuracy.

Time PM	User's Estimation location	Real Distance (m)	Information at Admin Smartphone	Accuracy (m)
8:50	near to Chicken Cottage by 4 m	2.5	near to Chicken Cottage by 4 m	1.5
8:55	near to Jungle Land by 7 m	5	near to Jungle Land by 7 m	2
9:00	near to Mangel Plus by 9 m	7	near to Mangel Plus by 9 m	2
9:05	near to Super Star Restaurant by 5 m	3	near to Super Star Restaurant by 5 m	2
9:10	near to Carnval Cinema by 4 m	1.6	near to Carnval Cinema by 4 m	2.4

Table 6 System Accuracies.

System	Accuracy(m)
Global Positioning System (GPS), **Hightower,** and **Borriello, 2001**.	10
Indoor Localization of Mobile Device for a Wireless Monitoring System based on Crowdsourcing**, Balas, 2011**.	7
A Reliable and Accurate Indoor Localization Method Using Phone Inertial Sensors, **Li, 2012**.	2
Robust Indoor Localization on a Commercial Smartphone**, Kothari, et al., 2012.**	5
Evaluation of Wi-Fi-based Indoor (WBI) Positioning Algorithm**, Aboodi, and Wan, 2012.**	2.6
The Proposed System.	≈2.1

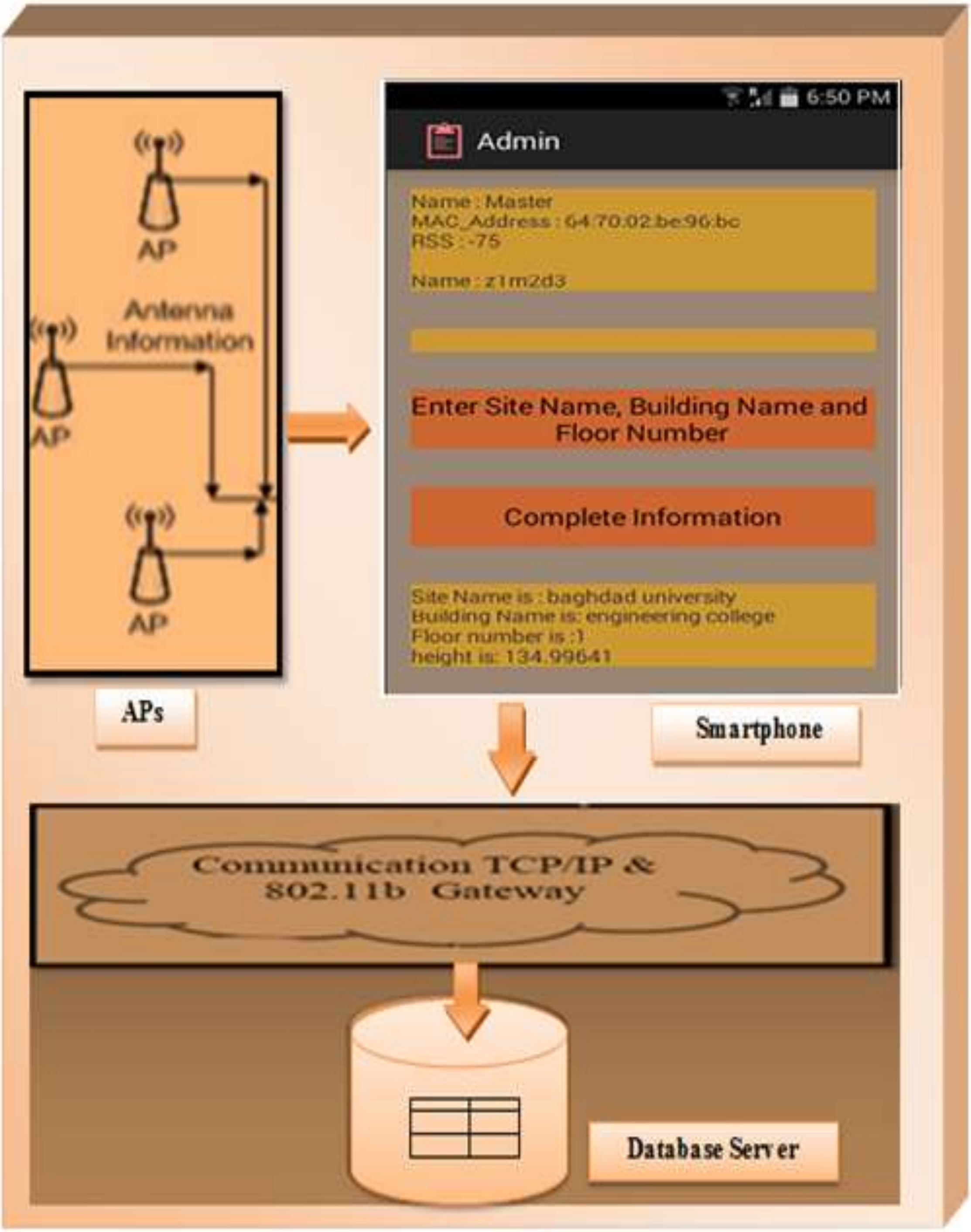

Figure 1 .Training Phase.

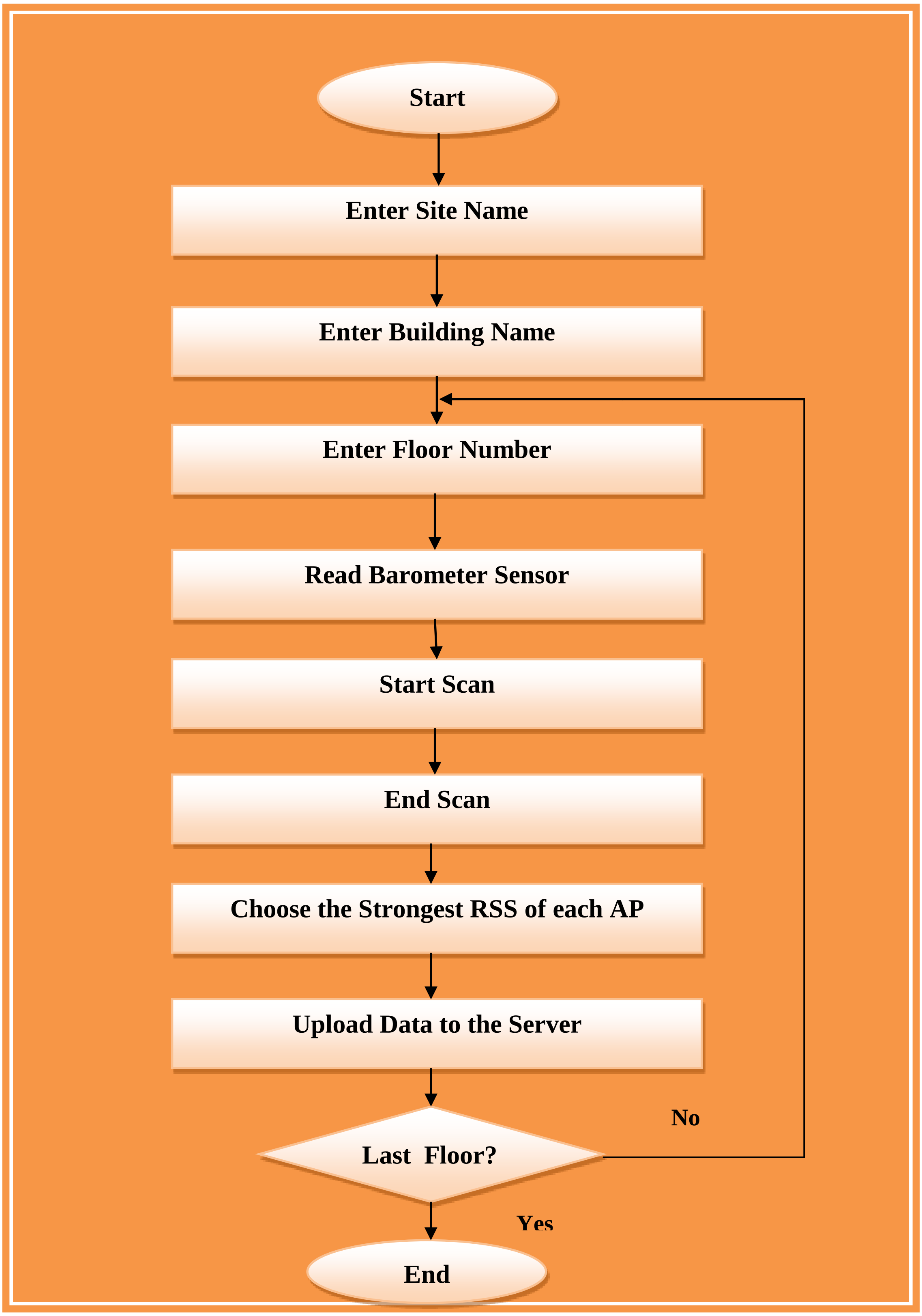

Figure 2. Flowchart of Training Phase.

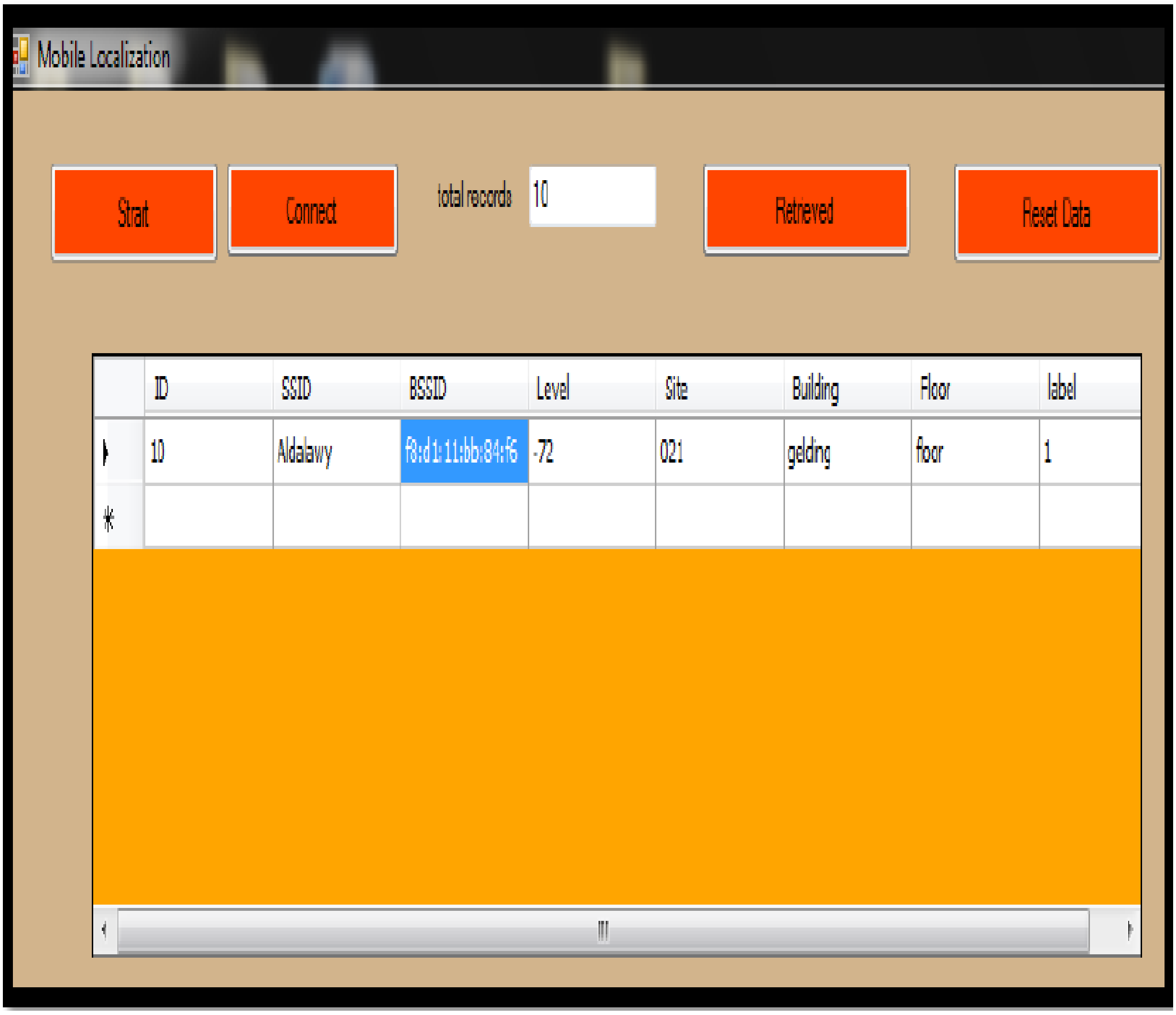

Figure 3. Database Entries.

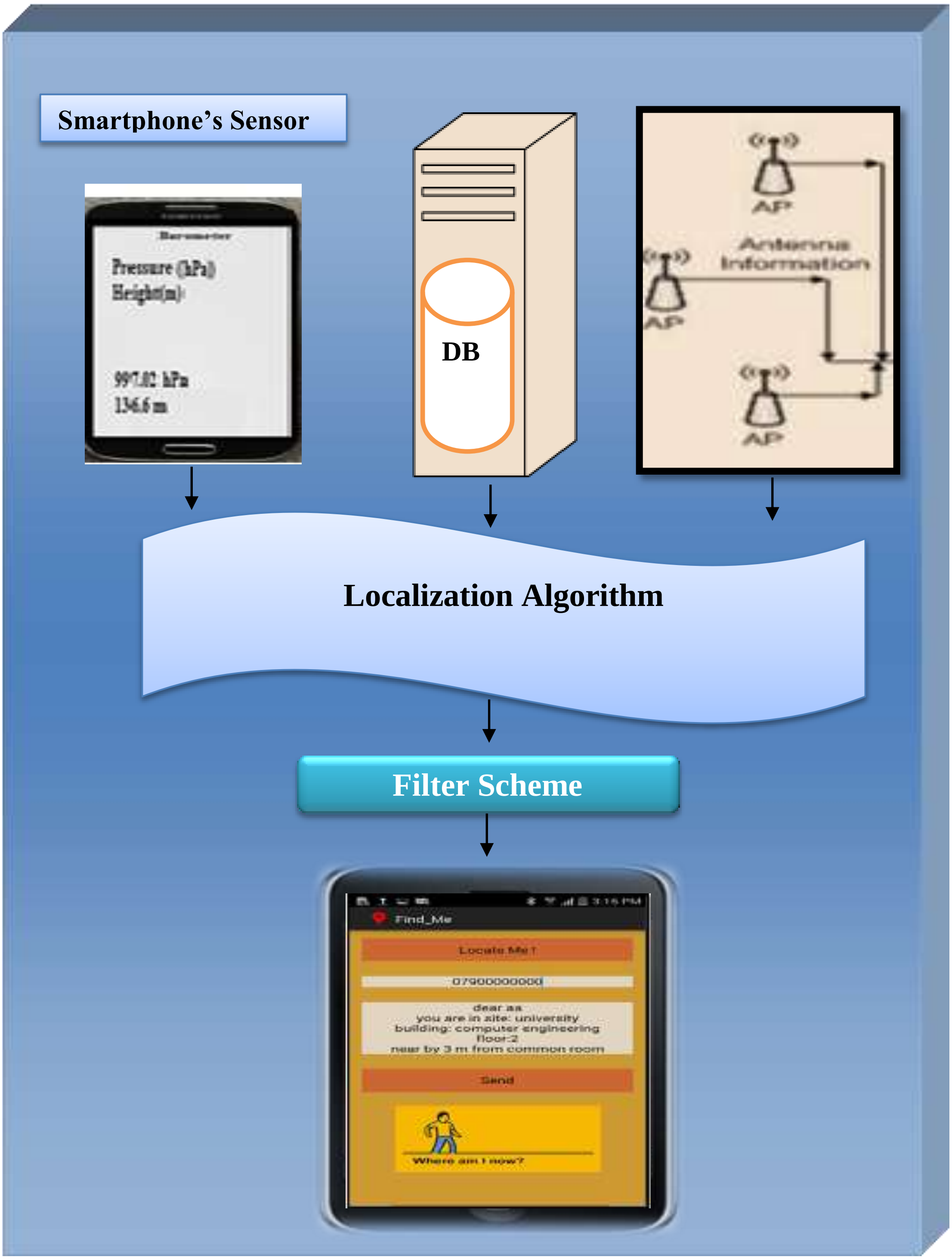

Figure 4. Localization Phase (Locate Me Service).

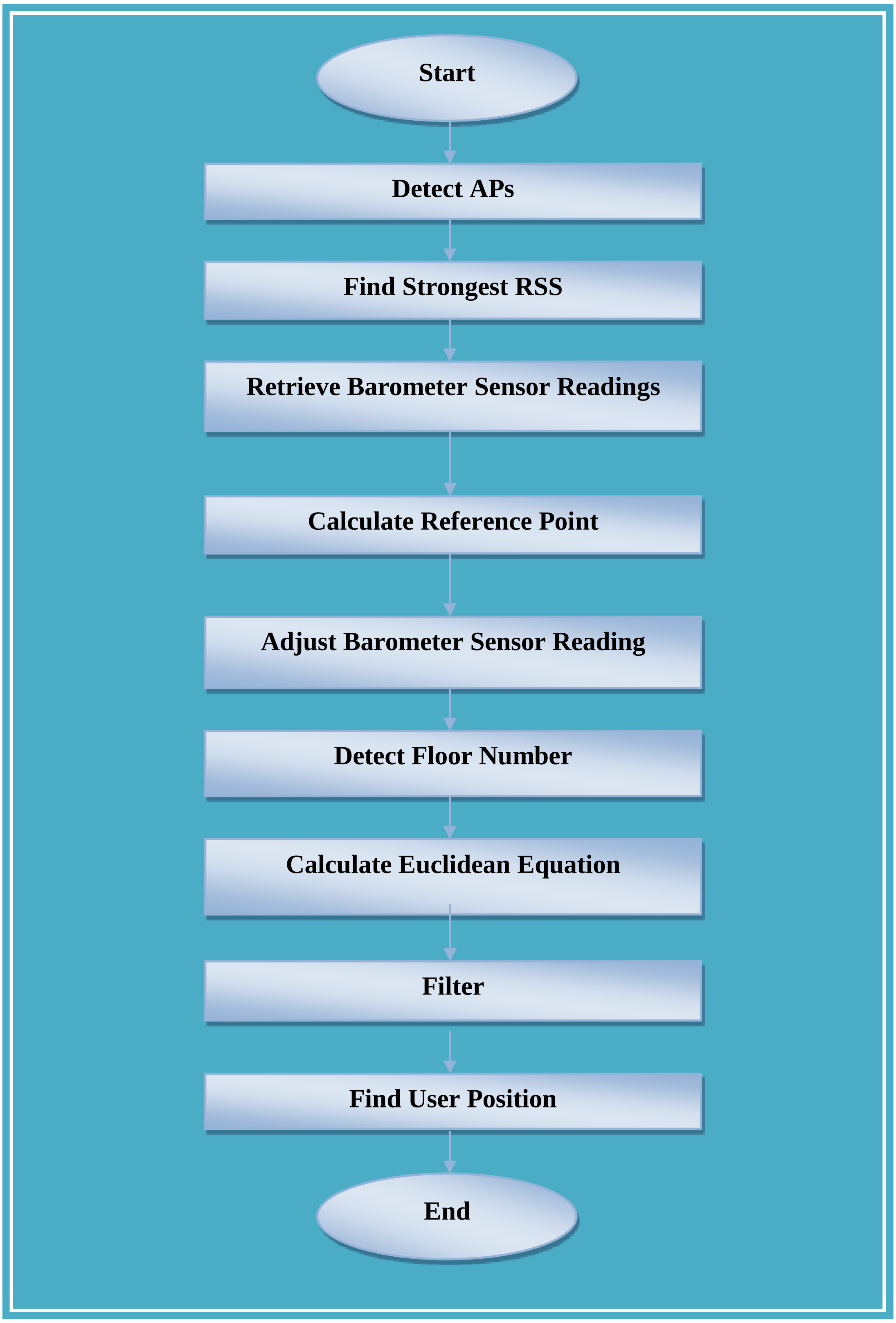

Figure 5. Flowchart of Localization Phase.