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FLOOR IDENTIFICATION USING SMARTPHONE BAROMETER SENSOR FOR INDOOR POSITIONING

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ABSTRACT

Indoor positioning has emerged in recent years for providing location based services for localization, tracking and navigation systems. Indoor positioning in smartphones has become possible with the availability of good processors, sensors and connectivity in smartphone. Floor identification is an important aspect of indoor positioning. This paper proposes a method to overcome the altimeter error caused by atmosphere erratic changes with time; thereby it improves the positioning accuracy of the user height. The relationships among the atmospheric pressure, the absolute height, and the floor location are described along with a real-time calibration method using smartphone Barometer sensor. The proposed method is tested in a building consists of seven floors and quite very good accuracy has been achieved.

KEYWORDS: Barometric Altimetry, Smartphone Sensor, Indoor Positioning, Floor Identification and Barometer Sensor.

INTRODUCTION

Floor determination is challenging subject in multistory building in indoor positioning systems. Many approaches have been adopted to cover this task; some of them depend on the received signal strength (RSS) of Wi-Fi Access point to detect the floors in the multistory building such as in [1] an indoor positioning system is designed based on a cluster of Wi-Fi Access points and the infrastructure information technology. Whereas in [2] an enhancement occurred on the RSS method through predicating and measuring fingerprint of Wi-Fi signals based on nearest neighbor and particle filter algorithms. Furthermore, in [3] two studied methods of Wi-Fi based models have been presented; the k-nearest neighborhood and the group variance algorithms are used to detect floors in the multistory buildings. However these methods suffer from large errors at non-ideal settings, high computational complexity, requirements of intensive database access, complex pre-calibration procedures, an AP that was measured during the calibration phase might not be received during the operation phase and vice versa, and increase in data traffic at Wi-Fi access points**.** Also, other approaches depend on the RFID method to detect floors in the multistory building have been presented such as in [4] an indoor positioning system based on a passive RFID tags has been presented. However, this method requires a pre-installation of infrastructure network of RFID tags; as well as the precision of estimation depends on the density of the tag installation, which presents a high cost for working in a certain practical environments. Furthermore, a portable device embedded with an RFID tag reader must be carried by the user and a certain level, approximately 8m, of system calibration is required.

Recently, new approaches which depend solely on the Barometer sensor have been applied to detect floor level. The results show the building floors can be determined by using the Barometer device. Actually, the purpose of this work is to analyze and identify the drawbacks of the latest research found in using Barometer sensor to distinguish floor number, in multistory building, in indoor positioning. Also it proposes new approach which enhances and achieves accurate results than existing approaches.

The rest of the paper is organized as follows: Section II presents Theoretical Background, Section III presents Previous Work, section IV presents the

Proposed Approach, and section V presents the Hardware Platform, section VI presents the Performance Evaluation, sction VII presents the Important Metrics. Finally, section VIII presents the conclusion.

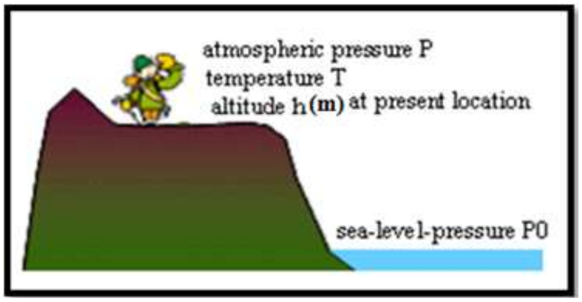
Theortical Background

Atmosphere pressure is the force per unit area exerted on a surface by the weight of air above that surface in the atmosphere of Earth (or that of another planet). There is a contrast relationship between the altitude and the atmosphere pressure at a present location; as altitude increases, atmosphere pressure decreases. In order to calculate the altitude at present location from the atmosphere pressure and temperature the following international formula is used [5]:

$$h=\frac{\left(\left(\frac{P_0}{P}\right)^{\frac{1}{5.257}}-1\right)*(T+273.15)}{0.0065} \quad (1)$$

Eq. (1) parameters are explained in fig. 1.

Fig. 1 Hypsometric Equation Parameter Details



It is worthy to mention that atmosphere pressure varies smoothly from the Earth's surface to the top of the mesosphere. Although the pressure changes with the weather, NASA has averaged the conditions for all parts of the earth year-round. The atmosphere pressure varies over day according to different parameters such as temperature, humidity, concentrate of gases, etc. [6]. Consequently, height value that is calculated from the atmosphere pressure using Eq. (1) is prone to error because the variance in atmosphere pressure presents different height values. In other words, height value calculated at specific hour such as 10 O'clock morning is different from the height value that is calculated at another hour such as 12 O'clock afternoon for the same floor at the same building. Therefore, each time new height value is calculated, using Eq. (1), new updated values for pressure and temperature have to be applied in Eq.(1) to obtain accurate height.

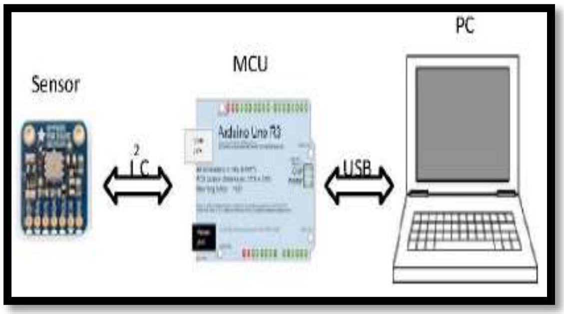
PREVIOUS WORK

There have been a number of solutions that tried to address the floor identification issue inside a building. However, most efforts have focused on the usability aspect of the problem and have failed to develop innovative techniques that address the essential challenge of this problem: the atmosphere pressure variance over day. This section describes various techniques for floor identification based on Barometer sensor reading that has been researched. These techniques are briefly explained as follows:

A. *Helping the Blind to Find the Floor of Destination in Multistory Buildings Using a Barometer [7].*

This technique uses a miniature barometer in the form of a low-cost MEMS chip connected through a 12C bus to an Arduino Uno-R3 board [8]; and the Arduino board is connected to a laptop computer using a standard USB cable to detect floor, fig. 2 shows the block diagram of hardware platform design.

Fig. 2 Block diagram of hardware platform design



Sensor chip BMP085 is used for the pressure calibration purposes. When pressure P is measured and a reference pressure P_0 at a measurement station (e.g., a weather station) within a certain distance from the test location is provided, the altitude (in meters) at the measurement site can be calculated using Eq. (2):

$$\text{Altidue}= 44330 * \left(1 - \left(\frac{P}{P_0}\right)^{\frac{1}{5.255}}\right) \quad (2)$$

Where the measurement of temperature is substituted into the calculation of pressure. In order to use this technology in practice, several sub-systems will need to be developed. For example databases, which include the height information of each floor, will need to be established for buildings according to either actual measurements or the construction documents. However, this method creates a burden on the user because an embedded system is needed for each user to be able to detect floor. In addition a reference pressure (from weather station) is needed which results in increasing the overhead.

B. *Differential Barometric Altimetry Assists Floor Identification in WLAN Location Fingerprinting Study [9].*

This system uses a differential barometric altimetry method based on the air pressure sensor in a smartphone to detect floor. It gets altitude for identification from filtering and calculating the air pressure data which is uploaded real time by both base station and mobile station and the base also support temperature data. This system uses Laplace formula for height computation as shown in Eq. (3):

$$\mathrm{H}= H_{0} + 18410 * \left(1+ \frac{Tm}{273.15}\right) * log\frac{P_0}{P} \qquad (3)$$

Where T_m is the average temperature between isobaric surface P_0 and P, $T_m = \frac{T_{0+T}}{2}$, T_0 is temperature of base station, T is from measurement result.

If H is wanted, P and T from mobile and H_0, P_0 and T_0 from base station must be known. Take indoor into consideration, temperature could be calculated as T_m = T_0= T. Fig. 3 shows the procedure of differential barometric altimetry assist floor identification.

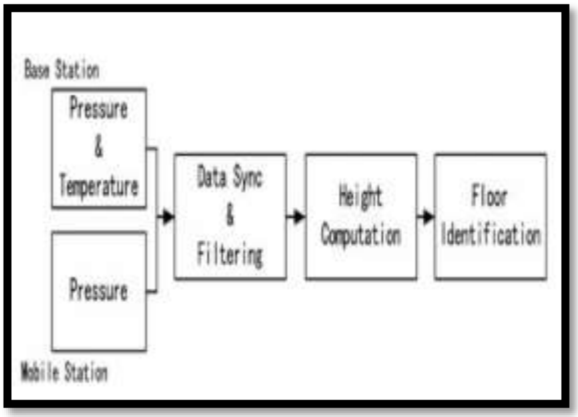


Fig. 3 Procedure of DBA Assist Floor Identification

It supposes the H_0 =0 and P_0 = 1000 hpa then Eq. 3 becomes:

$$\mathrm{H}= 18410 * \left(1+\frac{T_m}{273.15}\right) * (3 - lg\, P) \qquad (4)$$

However, as mentioned in this paper [10], this method does not take into consideration the atmosphere's variability over day which leads to incorrect floor detection.

C. *Concept for building a smartphone based indoor localization system [10].*

This technique uses the BMP180 from Bosch which is installed in the experimental unit and can be used in the indoor navigation as floor detection. To this end, the detected air pressure P_i is converted with the barometric height as in Eq. (5) into relative height h_i. For the barometric equation, the sea level with a local middle atmosphere is used as a reference.

$$h_i = \left(1 - \sqrt[5.255]{\frac{P_i}{1013.25}}\right) * \frac{288.15}{0.0065} \quad (5)$$

For floor recognition, a staircase in Building D of the HafenCity University (HCU) was used. The measurement range was over all four floors. The testing device register continuously measured data through its own application, the floors were walked along. On each floor the device was positioned 4 minutes. The floors were visited with the sequence 4-3-2-1-1-2-3-4. However, as long as this technique did not take into consideration the atmosphere pressure variance over day, therefore, this approach leads to incorrect floor identification.

PROPOSED APPROACH

The proposed approach is merely based on smartphone barometer sensor to identify floor level, in multistory building, for indoor positioning systems. The proposed approach consists of two phases: the Offline (training) phase and Online (localization) phase. The Offline phase is used to record the smartphone barometer reading of each floor in the building and then sent to be stored at the database server. The Online phase is used to determine in which floor number the user may exist. The Online phase is first extracting currently smartphone barometer reading of the user, subject to localization, and then in conjunction with retrieved offline barometer readings, the user floor number is determined.

A. *Offline Phase*

Fingerprint mechanism is used in the Offline phase to deal with Barometer sensor readings. A Smartphone, in the Offline phase, is used to detect the pressure that is used to calculate the height value for each floor and send the height to be stored at the database server. Height value is calculated from the pressure using the international standard form mentioned in Eq (1).

Where the temperature parameter T is taken from the smartphone temperature sensor, reference pressure parameter P_0 is the pressure value at sea level which is equal to 1013.25hpa, and the pressure parameter P is the real time pressure which is extracted from the smartphone pressure sensor. Note that, each floor has its own pressure and height values that are different from the other floors. Hence, each floor stored at the database server, is uniquely identified by its associated height values. The purpose of storing height values, for each floor, will be explained and analysed later in the Online phase. Fig. 4 shows the flowchart of the Offline phase for detecting and storing barometer readings for a building. Note, the Offline phase can be performed at any time during the day.

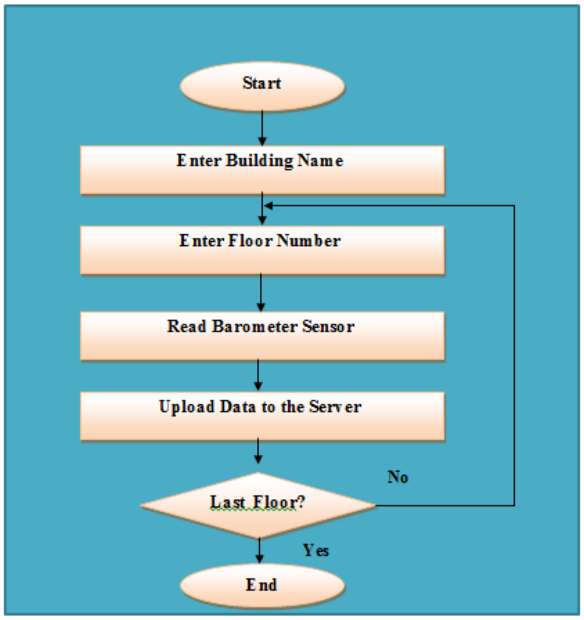


Fig. 4 Flowchart of Offline Phase

B. *Online Phase*

As mentioned and referenced in section II, it is important to note that, the Barometer sensor reading is changing with time. Suppose the Barometer sensor has a height value, at certain floor, equal to 150.5 m at 10 O'clock morning. This value will be altered, in another time of the day, according to the change in the parameters: pressure, temperature and humidity. Thus, the Barometer sensor may have different reading after an hour. Changing in height may be increased or decreased according to the parameters mentioned above. This phenomena results in producing error when the Online phase occurs at atmosphere environment, at the same time or another time of other days, different from Offline phase atmosphere environment.

The proposed approach fixes this problem through storing the Barometer sensor reading at each floor in the database server, during Offline phase, arranged from the first floor to the last floor of a specific building. Now, during the Online 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 training phase using Eq. (6), and the result represents the difference between the two values. This difference represents a new value called "Reference Point (RP)", the new value is subtracted from the all Barometer sensor readings using Eq. (7) of each floor, which are previously detected and stored at the database server during the Offline phase.

$$\mathrm{RP} = Height_{Online\ 1} - Height_{Offline\ 1} \qquad (6)$$

$$Height_{Estimated\ Height\ i} = Height_{Online\ i} - RP \qquad (7)$$

Where i represents the floor number. In order to clarify the idea of the proposed approach, a practical test is conducted in a mall consisting of seven floors. The Offline phase was performed at 12:30 O'clock afternoon; while the Online phase was performed at 6 O'clock evening. Table 1 shows the smartphone barometer values during the offline and Online phases, respectively. In addition it shows the RP produced from applying Eq. (6), together with new height values produced from applying Eq.(7) for each floor at Online phase. For example, suppose during the Online phase the user is at floor 4 that has Barometer reading equal to **51.17m** shown in Table 1. The calculated new height value, for floor 4 shown in Table 1 is **35.31m**, is compared with all Offline Barometer floor values. Then floor 4 is recognized because it has less difference value between its Offline phase value and its new height value. The estimated height 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 RP is calculated and the above mentioned equations are applied again. Fig. 5 shows the flowchart of the localization phase.

Floor Number	Barometer Sensor Values during Offline Phase (m)	Barometer Sensor Values during Online Phase (m)	RP (m)	Estimated Height Values (m)
1	21.85	37.71	15.86	21.85
2	26.83	43.05	15.86	27.19
3	31.07	48.1	15.86	32.24
4	35.78	51.17	15.86	35.31
5	39.48	54.06	15.86	38.2
6	45.06	59.87	15.86	44.01
7	48.2	63.48	15.86	47.62

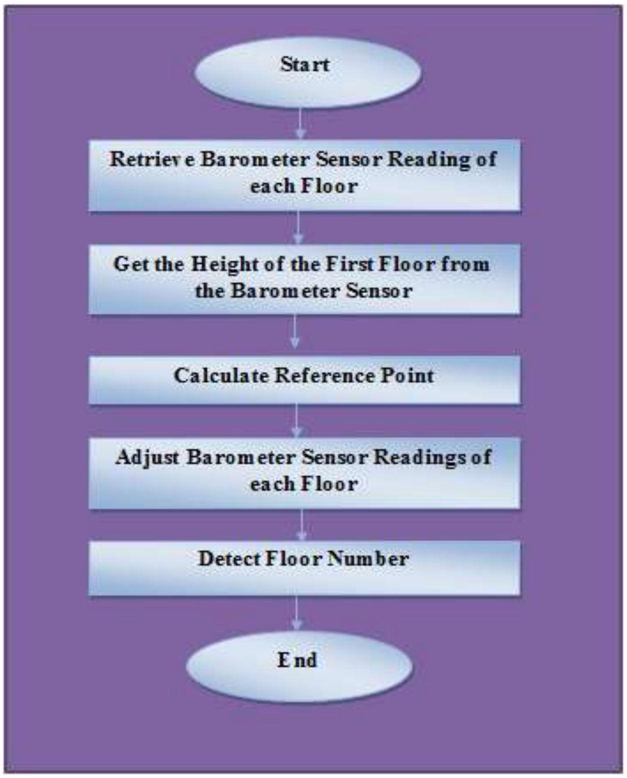


Fig. 5 Flowchart of Online Phase

HARDWARE PLATFORM

The proposed system implemented with the Android based java programing language using Samsung Galaxy S4 smartphone, the version of the target library is 4.4.2 “KitKat”. Samsung Galaxy S4 smartphone has a Barometer sensor known as BMP180 which is the new digital barometric pressure sensor of Bosch Sensortec, with a very high performance. It follows the BMP085 and brings many improvements, like the smaller size and the expansion of digital interfaces [11].

Performance Evaluation

The proposed solution was tested in a Mall consisting of seven floors; the Offline phase was performed at 12:30 O’clock afternoon for each floor while the Online phase was performed at 6 O’clock evening. The results are shown previously in Table 1; fig. 6 shows the relationship among the Offline phase, Online phase and the estimated height for each floor.

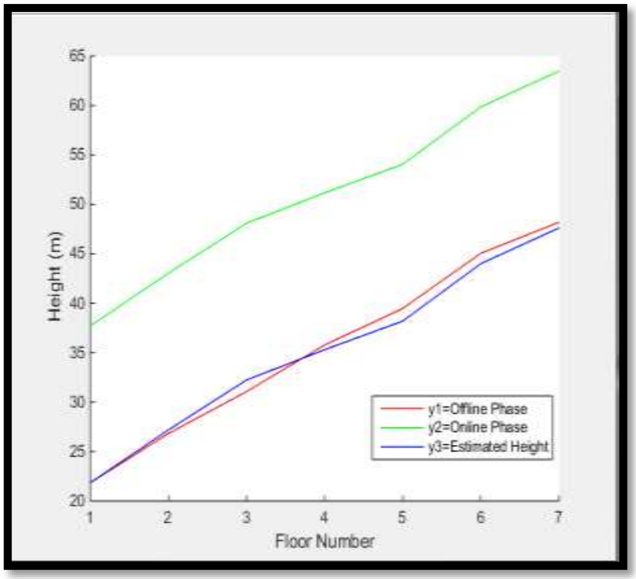


Fig. 6 Relationship among the Offline phase, Online phase and the Estimated Height

Where green line represents the Online phase conducted at each floor, the red line represents the Offline phase conducted at each floor and the blue line represents the estimated height which is calculated from Eq. (6) and Eq. (7). In order to prove and clarify that the proposed approach is working properly, another test was performed in the mall for the second floor in different times of another day. Table 2 shows the results of the test conducted at second floor. This table is based on the offline phase floor values presented in Table 1.

The first column represents the number of times that the test is conducted at the second floor in different times, the second column represents the time of the test, the third column represents the Online phase which is conducted at the first floor in different times. These values, Online phase values of the first floor, are necessary to calculate the RP using Eq. (6).

Number of Test	Time	Online Phase at First Floor	Online Phase at Second Floor	RP	Estimated Height at Second Floor
1	8:30 am	23.6m	28.55m	1.75m	27.56m
2	9:30 am	25.42m	29.31m	3.57m	25.74m
3	11:35 am	27.76m	33.01m	5.91m	27.1m
4	1:50 pm	53.03m	58.89m	31.18m	27.71m
5	3:30 pm	59.99m	63.76m	38.14m	25.62m
6	4:47 pm	72.25m	78.02m	50.4m	27.62m
7	6:00 pm	75.74m	80.89m	53.89m	27m
8	7:05 pm	79.4m	83.65m	57.55m	26.1m
9	9:21 pm	89.87m	95.09m	68.02m	27.07m
10	10:40 pm	95.14m	99.83m	73.29m	26.54m

Table 2. Results Conducted at Second Floor

The fourth column represents the Online phase which is conducted at the second floor in different times, the fifth column represents the RP. Finally, the sixth column represents the estimated height of the second floor which is calculated using Eq. (7). In more details, taking the first case shown in Table 1, the Offline phase for the first floor was approximately equal to the Offline phase value of the second floor, **26.83**, as shown in previously in Table 1.

To prove that this approach is working properly, we can conclude from Table 2 that the maximum difference between Offline phase height value and estimated height value of the second floor is 1.21m. Actually, it is well known, that the standard height of the building floors is not less than 3m. Hence, the obtained results are quite very good and do not exceed the building floors height value. Fig. 7 shows the relationship between the Online phase of the second floor and the estimated height of the second floor.

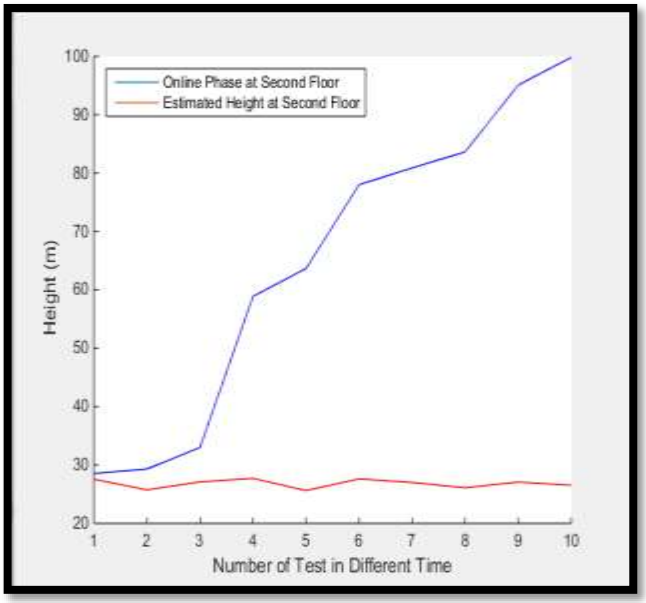


Figure 7 Relationship between the Online phase of the Second Floor and the Estimated Height of the Second Floor

IMPORTANT METRIC

Some of the important metrics have to be taken into consideration during the comparison of the proposed system with the other systems; these metrics are explained as follows:

1. **Platform**

This metric represents the type of the platform that the system is based on. Actually, it indicates whether the system uses the smartphone as a platform or there is additional hardware and external circuit that has to be augmented in the system. Clearly using smartphone as platform is much preferable than using any external circuit or additional hardware.

2. **Time of Operation**

The most important metric which forms the scope of this research is the time of operation. Actually, it indicates the validity of the system operation; however, most of the related work did not take into consideration the atmosphere's variability with time which affects the result and produces erroneous results.

3. **Reference Pressure (Weather Station)**

This metric indicates whether there is a reference pressure that has to be taken into consideration. Most of the related work based on the nearest weather station which can be used to provides the reference pressure; however this metric imposes a constraint on the system which is the distance that the weather station is far away from the indoor environments which means the system is restricted by the weather station availability.

Comparison between Proposed System and Related Works

As a summary, Table 3 demonstrates the important metrics of the proposed system compared with related work. These systems are outlined as follows:

1. Helping the Blind to Find the Floor of Destination in Multistory Buildings Using a Barometer [7].
2. Differential Barometric Altimetry Assists Floor Identification in WLAN Location Fingerprinting Study [9].
3. Concept for building a smartphone based indoor localization system [10].

Note, System 4, in table 3 represents the proposed system.

Implemented feature (√) **Not supported feature (X)**	**Systems**			
Important Metrics	**1**	**2**	**3**	**4**
Platform	X	√	√	√
Time of Operation	√	X	X	√
Reference Pressure (Weather Station)	X	X	√	√

Table 3. Comparison between Proposed System and Related Works

The important metrics of each system are analyzed as follows:

1. System 1 based on an external circuit as explained previously in section III as a platform which increases the overhead on the user; therefore the platform metric is not supported. It depends on the weather station for providing the reference pressure as well as the pressure of the first floor to fix the problem of the system validity; therefore, the time of operation metric is implemented. Finally, depending on the weather station forms additional constraint on the system; therefore, reference pressure metric is not supported.
2. System 2 based on Samsung I9300 android smartphone as a platform; therefore; the platform metric is implemented. It does not take into consideration the atmosphere variability which limits the validity of the system; therefore, time of operation metric is not supported. Finally, it depends on the weather station in its calculations; therefore, reference pressure metric is not supported.
3. System 3 based on Nexus 4 android smartphone as a platform; therefore; the platform metric is implemented. It does not take into consideration the atmosphere variability which limits the validity of the system; therefore, time of operation metric is not supported. Finally, it does not depend on the weather station in its calculations; therefore, reference pressure metric is implemented.
4. System 4, proposed system, based on Samsung Galaxy S4 android smartphone as a platform; therefore; the platform metric is implemented. It takes into consideration the atmosphere variability as explained in details in section IV which makes the system valid all the time; therefore, time of operation metric is implemented. Finally, it does not depend on the weather station in its calculations; therefore, reference pressure metric is implemented.

CONCLUSION

In this paper, floor detection based on smartphone Barometer sensor is presented which is flexible for using at any building for the purposes of indoor positioning and indoor navigation systems. The proposed approach eliminates the problem of Barometer sensor readings variations in different times of the day without needing of any reference pressure (weather station), temperature or any additional hardware. The experiment shows the ability of using our proposed system, in the indoor positioning systems, to detect user's floor in a certain building.

For the future work, the proposed approach has the partial restriction of activating the system in the first floor of the building to calculate the reference point. To make the system more flexible and eliminate this restriction, other parameters (such as accelerometer, compass and gyroscope sensors) could be investigated to overcome this restriction.

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