Differential Barometric Altimetry Assists Floor Identification in WLAN Location Fingerprinting Study

Keqiang Liu, Yunjia Wang and Jian Wang

Abstract Floor identification is an important aspect of indoor positioning while the resolution of altimetry is not very well, especially in WLAN Location Fingerprinting System. This chapter presents a differential barometric altimetry (DBA) method to identify floor in consideration of features of WLAN location fingerprinting system and the air pressure sensor in a smart mobile phone. The method is that 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. The result of experiment shows the resolution of sensor is fairly high and filtered data is steady, the altimetry resolution is about 0.2 m, precision is less than 0.5 m, accuracy is about 1.0 m. All about the experiment indicate the method is fit for floor identification in indoor positioning.

Keywords Differential barometric altimetry · WLAN location fingerprinting · Indoor positioning · Floor identification

1 Introduction

GNSS has been applied very broadly with features like high precision, all-weather and high efficiency in open environment (Kaplan Elliot and Hegarty Christopher 2006; Xu et al. 2008), but it doesn't work well for indoor users as for problems that weak signal strength and multipath (Retscher and Kealy 2005). While there are many methods (Retscher and Kealy 2005; Bill et al. 2004) for indoor plane positioning because of development in this field, there hasn't been good solution for floor identification during position. In WLAN location fingerprinting, as information of floors has already been record in database or fingerprinting

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(Deng et al. 2012), users can know on which floor they are, and the result is low accuracy and precision. Barometric altimetry is a traditional method which is widely used in outdoor (Huo 1997; 2002). As for indoor surroundings, atmosphere isn't that variable, so using the method to identify floors is quite suitable. Meanwhile, Smartphone is a good platform for WLAN positioning users and sensors in Smartphone are strongly assistants for location.

Deng and his team used K-means algorithm and features of AP signal in different floors to cluster after fingerprint data training and got the floor information during location time (Deng et al. 2012). This method can increase the efficiency but the accuracy is not well. Du and his colleagues presented differential barometric altimetry method based on mobile phone base stations to assist GPS positioning, which mentioned the method could be used in indoor location (Du et al. 2013). Paper Hu and Zhang presented by Hu and Zhang (2012) is involved with differential barometric altimetry (DBA) and indoor location, but designing and analysis of sensor block is their point.

Many chapters have mentioned the differential barometric altimetry method could be used in indoor location, but there haven't been details of using. This chapter presents DBA assist floor identification in WLAN location fingerprinting with consideration of WLAN positioning system and pressure sensor of smartphone: get and upload the pressure and temperature data of base station in real time, filter data and compute altitude when mobile station calling for location, identify and sent the result.

2 Barometric Altimeter and Principles

Barometric altimeter is a traditional method for altitude measurement, based on atmosphere pressure or barometric pressure decrease when altitude increasing (Huo 1997; 2002). So it can get the altitude from measure pressure and high-pressure model. According to the theory of atmosphere physics (Xu et al. 1993), the vertical movement of atmosphere is pretty small, so it can be approximated that in static equilibrium state. That means force in the horizontal direction cancel each other while the net upward pressure in the vertical direction equilibrium with its own gravity, and then it draw the formula of atmosphere statics as follows:

$$dP = -\rho \cdot g \cdot dz \tag{1}$$

where dP is net upward pressure, ρ is the density of atmosphere, g is the local acceleration of gravity, dz is the thickness of atmospheric block and the cross-sectional area is 1 m^2.

State equation of ideal gas:

$$PV = nRT \tag{2}$$

where P is pressure value, V is volume, n is the molar number, R is a constant, T is the temperature in Kelvin.

Let P_0, P_1 be the pressure of height z_0 and z_1, the high-pressure formula can be obtained for above two:

$$\int_{P_0}^{P_1} \frac{dP}{P} = -\int_{z_0}^{z_1} \frac{gdz}{RT} \tag{3}$$

or

$$P_1 = P_0 e^{-\int_{z_0}^{z_1} \frac{gdz}{RT}} \tag{4}$$

It can be concluded that pressure decrease exponentially with height increasing (Xu et al. 1993).

Generally, R and g with little change in z, but T has a significant change with z. Because we can't get the exact formula of T and z, so we need some assumptions to atmosphere like isothermal atmosphere, diverse atmosphere and standard atmosphere. The Laplace formula is usually used in measurement:

$$H = H_0 + 18410\left(1 + \frac{T_m}{273.15}\right) \lg \frac{P_0}{P} \tag{5}$$

T_m is the average temperature between isobaric surface P_0 and P_1 or $T_m = \frac{T_0+T}{2}$, 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 must be known. Take indoor into consideration, temperature could be calculated as $T_m = T_0 = T$.

Let $H_0 = 0$, and $P_0 = 1000$ hPa as for near the ground (Xu et al. 1993), then formula (5) comes to:

$$H = 18410\left(1 + \frac{T_m}{273.15}\right)(3 - \lg P) \tag{6}$$

The altitude change with pressure in different temperature is illustrated in the Fig. 1 below:

Generally, pressure decrease exponentially with height increasing. The higher temperature is, the faster velocity becomes, excluding the influence of the temperature on pressure. Figure 1b indicates: the trend is approximately linear near P_0. When temperatures between −25 and 50 °C and near the ground, height change about 0.72–0.94 m when pressure changing 0.1 hPa. When temperature is 25 °C, the height change is about 0.87 m.

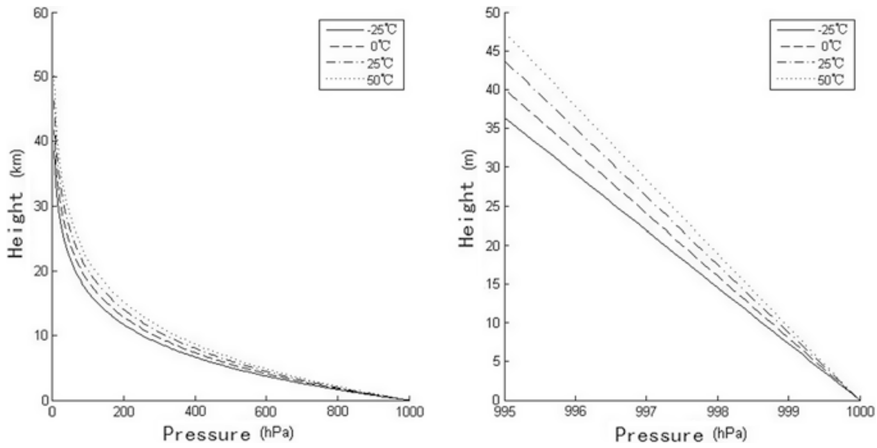


Fig. 1 Trend of altitude with pressure in different temperature

3 Differential Barometric Altimetry Assists Floor Identification

3.1 WLAN Location Fingerprinting and Its Floor Identify

WLAN location fingerprinting is a process of machine learning depends on WLAN signal, it locate on the database, which is structured during the so–called sampling or offline step. And then the locating/online phase, different location result from different machine learning algorithm or from the weighted value of several locations, the computation usually on server for large amount. Despite of the computation burden, the sight limitation is avoided and the multipath is used.

There are two ways to identify floor during WLAN location, first one is using signal fingerprinting with floors information while other one is to achieve altitude or variation relating to altitude just like this chapter presents.

3.2 DBA Assists Floor Identification

Pressure comes from the atmosphere which is changing continuous, so pressure changing all the time. For various feature, altitude from mathematical height-pressure model is not that accuracy. In traditional application of model, it controls the error by setting calibration stations (Huo 2002). It will establish base station to get the pressure and temperature data real time in indoor location. When it comes online locating, user will upload the WLAN signal and the pressure data, the former is for plane coordinates, the latter is for floor identification.

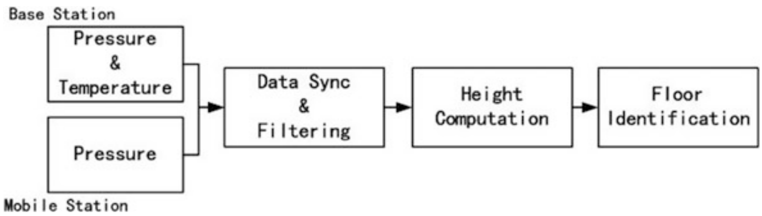


Fig. 2 Procedure of DBA assist floor identification

In indoor circumstances, temperature is familiar for short distance, that is the base for consideration of temperature influence is synchronous or $T_m = T_0 = T$. Other factors like humidity, acceleration of gravity act as familiar as temperature does. Meanwhile, all the data from base and mobile is real time. All above induce a better result of height. Given that the altitude of base station is known, user will get accurate altitude. Figure 2 illustrate the procedure of DBA assist floor identification.

4 Experiment and Data Analysis

4.1 Place and Platform

The data were collected in school building 1–5th floor of Spatial Informatics in China University of Mining and Technology. The platform is Samsung I9300 android smartphone, the pressure sensor of it is LPS331AP block produced by Stmicroelectronics Corporation.

The 24 h data were from three different phones' pressure sensors, which were separated into two parts. Two of phones in a part which had same altitude with about 30 m distance while other part of two phones had same plane coordinate with different altitude about 8 m height. The Fig. 3 illustrates the result. From the figure it can conclude that the trends of pressure are consistent whether on part one or part two. The conclusion also is the condition for barometric altimeter and DBA.

4.2 Resolution of Pressure Sensor and System Stability

From the data sheet of LPS331AP (2012), the barometer absolute pressure ranges from 260 to 1260 hPa, and in the high–resolution mode the RMS is 0.020 hPa. According to former discussion, the height resolution is about 0.2 m during −25–50 °C. Floor height always is about 3–4 m, so the sensor can identify floor.

Figure 4 indicates pressure values have shakes though the trends are consistent. For more details, this chapter takes data of sensor 1 from 12:50 to 03:50 illustrated

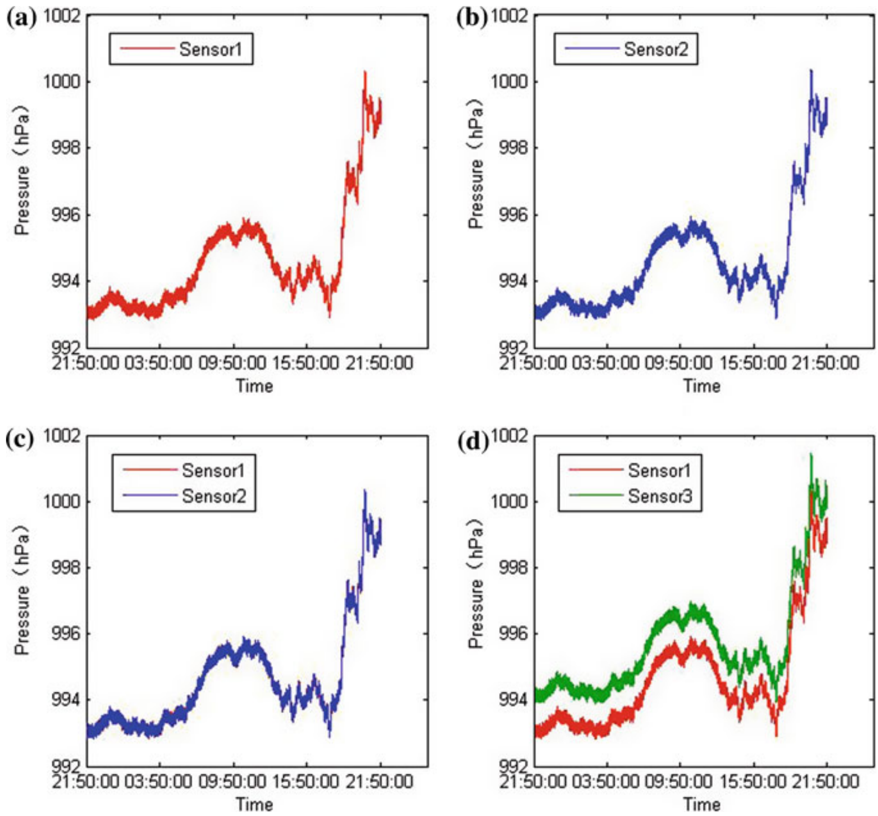
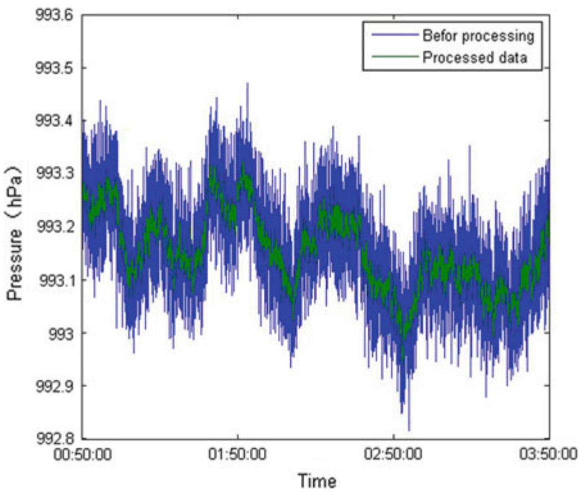


Fig. 3 Pressure data of 24 h

Fig. 4 Data before filtering and data processed



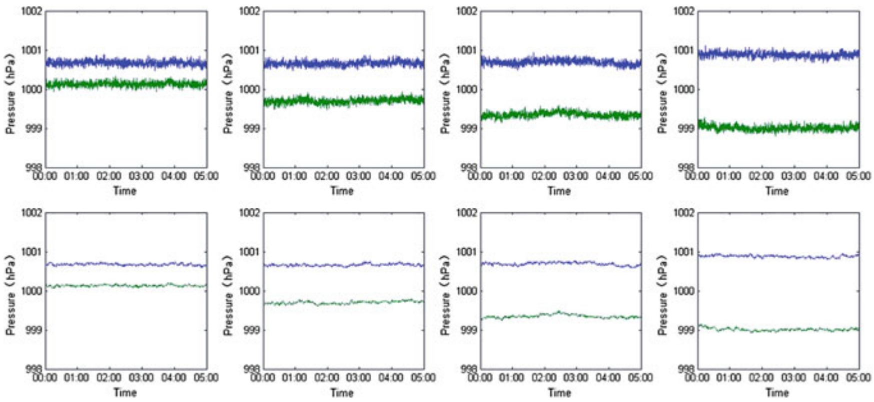


Fig. 5 Raw data and filtered data of each mobile station with base

Table 1 Error statistics (Unit: m)

Actual height	Mean height of computation	Standard deviation of computation	RMS
5.00	4.85	±0.28	0.32
9.00	8.59	±0.32	0.52
13.00	12.00	±0.37	1.06
17.00	16.72	±0.41	0.49

in blue line in the figure. To reduce shakes and increase the accuracy, this chapter use a low pass filter model [formula (7)] to filter the noises. The dark green line is the result, which is more stable and has less noise.

$$Y_n = aX_n + (1 - a)Y_{n-1} \tag{7}$$

where Y_n is the output of current filter, X_n is current data, Y_{n-1} is the output out last time, a is a constant ranges from 0 to 1, this chapter let a = 0.125.

4.3 *Precision and Accuracy of Altimeter*

The base station was in the hall on the 1st floor of school building to collect pressure and temperature. And the mobile station was a smartphone which moved from 2nd to 5th floor with a same model pressure sensor to collect pressure data. The frequency was 5 times every second and time lasted 5 min. The Fig. 5 is the result of data and filtered data, the first row are the data from base and mobile of same period, the second row is filtered data. Table 1 is the result of calculating from filtered data and the true values and the errors.

Table 1 indicates the standard deviation for precision of DBA less than 0.5 m, the RMS for accuracy of DBA is about 1 m. All the precision and accuracy are less than the floor height which often is 3–4 m, so the DBA method can be used to solve the floor identification problem. Meanwhile, pressure sensor assisting is a part of multi-sensor application in WLAN indoor location.

5 Conclusions

With popularity of smart city and urban wireless networks, WLAN Location System has a bright future. It is a good choice to use sensor system of smartphone to solve indoor positioning problem. This chapter presents a DBA method with using pressure sensor of smartphone to identify floor to improve the accuracy. The experiment indicates the method is able to improve the stability of output from sensors and give fairly high precision and accuracy height results, and the method can be used to identify floor in indoor location.

6 Future Work

During the experiment, atmosphere's variability affected the result had been found and will be cared, and how to apply this method in physical environment and how to use other sensors in smartphone (accelerator, gyroscope, orientation) are the future directions.

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