Published in final edited form as:
Conf Proc IEEE Eng Med Biol Soc. 2013 July ; 2013: . doi:10.1109/EMBC.2013.6610606.

Helping the Blind to Find the Floor of Destination in Multistory Buildings Using a Barometer

Yicheng Bai[1], **Wenyan Jia**[2], **Hong Zhang**[3], **Zhi-Hong Mao**[1], and **Mingui Sun**[1,2]
[1]Department of Electrical & Computer Engineering, University of Pittsburgh, Pittsburgh, PA 15213, USA

[2]Department of Neurosurgery, University of Pittsburgh, Pittsburgh, PA 15213, USA

[3]Image Processing Center, Beihang University, Beijing, 100191, China

Abstract

Propelled by rapid technological advances in smart phones and other mobile devices, indoor navigation for the blind and visually impaired individuals has become an active field of research. A reliable positioning and navigation system will reduce suffering of these individuals, help them live more independently, and promote their employment. Although much progress has been made, localization of the floor level in a multistory building is largely an unsolved problem despite its high significance in helping the blind to find their ways. In this paper, we present a novel approach using a miniature barometer in the form of a low-cost MEMS chip. The relationships among the atmospheric pressure, the absolute height, and the floor location are described along with a real-time calibration method and a hardware platform design. Our experiments in a building of twelve floors have shown high performance of our approach.

I. INTRODUCTION

The location information within a multistory building is critical for the blind and visually impaired individuals to find their ways [1], such as a doctor's office in a hospital or a classroom at a university. In this type of buildings, the determination of an indoor location generally involves two tasks: 1) finding the floor of destination, and 2) finding the specific location on that floor. Since the floor determination task is equivalent to adding an extra dimension (i.e., from (x, y) to (x, y, z)), various techniques have been reported to cover both tasks. Al-Ahmadi *et. al.* reported a Received Signal Strength Identification (RSSI) method relying on a cluster of Wi-Fi access points and an established infrastructure of information technology (IT) for indoor positioning,[2]. Widyawan *et. al.* enhanced the RSSI method by predicting and measuring fingerprints of Wi-Fi signals using the nearest-neighbor and particle filtering algorithms [3]. Alsehly *et. al.* studied two Wi-Fi based models using the k-nearest neighborhood and the group variance algorithms to detect floors in multistory buildings [4]. Although a sub-meter precision has been reported using the RSSI in height determination in ideal conditions, the RSSI method suffers from large errors at non-ideal settings, high computational complexity, requirements of intensive database access, complex pre-calibration procedures, and increase in data traffic at Wi-Fi access points. Ting *et. al.* proposed an indoor positioning system using passive RFID tags [5]. Although this method does not depend on Wi-Fi access points, it requires pre-installation of infrastructures, such a network of RFID tags. The precision of position estimation depends on the density of the tag installation, which implies a high system cost for a working system in certain practical settings. In addition, a portable device embedded with an RFID tag reader must be carried by the user and a certain level of system calibration is required.

Although indoor positioning has attracted much attention in the research community, most existing methods are mainly focused on localization in buildings with a single level or a small number of levels. Their precision in height determination is often poor due to the reflection and multipath effects of floors on electromagnetic fields. In this paper, we present a barometer based method for floor determination. This low-cost method reduces both the error and the dimensionality in indoor positioning systems for the blind and visually impaired individuals, eliminating the height determination task which is not needed by these people once they are on the floor of destination. As a result, the system runs faster and the output becomes more precise because of the reduced dimensions in the localization task.

II. METHODS

A. Theoretical Concepts

It is well known that the atmospheric pressure decreases as the altitude increases. The relation between atmospheric pressure, height, and temperature can be described by [6]:

$$h=(RT/gM)\ln(p_0/p) \quad (1)$$

where h is the difference between the starting height and the measurement height, R is the universal gas constant (0.31447J/(mol • k)), g is the gravitational constant at the earth surface (9.80665 m/s2 at the sea level), M is the molar mass of air (0.0289644 kg/mol), p_0 is the atmospheric pressure at the starting height (e.g., 101, 325 pa), T is the temperature of air, and p is the atmospheric pressure at the measurement height. In most weather conditions, many parameters in (1) change dynamically. In order to calculate the height difference accurately, all varying parameters must be updated in real time, which is a difficult task. Taking the molar mass of air for example, in order to obtain the real-time value for this parameter, the composition of air, which varies due to the atmospheric flow, must be known. Fortunately, most parameters do not change rapidly in time and space, such as the gravitational constant and the composition of air [7]. Therefore, in practical applications where a certain error is tolerable, we only need to consider the most significant parameters, which are temperature T, reference pressure p_0 and measured pressure p.

For the purpose of calibration, modern electronic altimeters usually allow inputs of at least a part of the parameters expressed in (1). Sensor chip BMP085 also includes these parameters stored in several pre-calibrated registers. According to the datasheets of BMP085 [8], when pressure p is measured and a reference pressure p_0 at a measurement station (e.g., a weather station) within an certain distance from the test location is provided, the altitude (in meters) at the measurement site can be calculated using the following international barometric formula [8][9]:

$$\text{altitude}=44330*\left(1-\left(\frac{p}{p_0}\right)^{\frac{1}{5.255}}\right) \quad (2)$$

where the measurement of temperature is substituted into the calculation of pressure.

B. Real Time Atmospheric Pressure

According to (2), a reference atmospheric pressure p_0 is required to obtain the altitude. Then, the relative height, which directly determines the floor level, can be obtained by subtracting the reference altitude at the first floor, which can be pre-measured and stored in a database, from the measured altitude. Once the relative height is determined, the floor location is the integer part of dividing the relative height by the known increment floor height of the building. The result may need to be corrected if the increment is not a constant.

In most municipalities in the U.S. and other countries, the atmospheric pressure, temperature, wind speed and direction, and air humility are measured at weather stations and broadcasted regularly. For our application, the reference atmospheric pressure data from the station nearest to the test point is obtained from the Internet since our wearable device (called eButton [10]), which hosts the BMP085 sensor, is equipped with a wireless channel. Alternatively, the pressure data from multiple stations can be weight-averaged to increase measurement accuracy. Figs. 2 and 3 show, respectively, the atmospheric pressure data from three weather stations (blue circles) near the test point (red dot) [11] and the pressure changes at the three stations in different days [12]. It can be observed from Fig. 3 that the atmospheric pressure at the same location may change slowly but significantly. However, since the data are usually continuous and smooth, a prediction algorithm, such as the Kalman filter, can be used to estimate the current value from past values when the real time measurement is not available. Fig. 4 compares a prediction result by the Kalman filter with real-time measurements. It is clear that accuracy of prediction is satisfactory.

C. Hardware Platform

The central component of our hardware platform is a barometer sensor chip BMP085 (Fig. 1b) which is a small size, low power, low noise, and high precision pressure sensor made by Bosch [8]. The measurement range of this sensor is between 300hPa and 1100hPa (equivalent to −500m to +9000m in altitude) which covers the entire land altitude range on earth. According to the data sheets of the manufacturer [8], the noise level of this chip is 0.03Pa (0.25m) in the ultra-high resolution mode. When an averaging algorithm is utilized, the noise level can be reduced to approximately 0.1m [8].

In order to apply the sensor chip to floor determination, we constructed a data collection platform. The block diagram of this platform is shown in Fig. 1a. The atmospheric pressure data from the BMP085 chip is connected through an I2C bus to an Arduino Uno-R3 board [13]. This board contains a Micro Controller Unit (MCU) (Type ATmega16U2, Atmel Corp.) and a number of peripheral components for memory, data inputs and outputs, and human interface. The output of the Arduino board is connected to a laptop computer using a standard USB cable. Software was developed for system control, data acquisition, and data management. The constructed hardware platform is shown in Fig. 1.

III. TESTS AND RESULTS

In our experimental study, a twelve-story building (the School of Engineering Building) was selected inside the campus of the University of Pittsburgh. In order to establish the ground truth data, we utilized a laser distance measurement instrument (Type DLR130, BOSCH, Germany) to measure the distance from each floor to a fixed location on the ground floor. In order to ensure that the laser beam was perpendicular to the base level, a string with a steel plumb Bob tied at the end was used to determine the measuring point at each floor. The measurement error was 1/16 inch according to the manufacturer’s datasheets.

Once the ground truth was established, we measured both atmospheric pressure and temperature data using the BMP085 barometer sensor and the constructed hardware platform. Raw data of the measured atmospheric pressure and the ambient temperature were stored as separate files in a laptop computer, which was connected to the Arduino board through a USB cable. Figs. 5 and 6 show the measured atmospheric pressure (right scale) and height data (left scale), respectively, in two different days. In these figures, each small change in slope (appears as a short “stair” with presence of noise) indicates a floor level. These were caused by a short stop of several seconds in each floor as the data collector walked up or down the stairways. It can also be observed from Figs. 5 and 6 that the measured pressure data (the right scale in each figure) differs in different days. This indicates that the pressure data must be calibrated according to the reference pressure information.

In both Figs. 5 and 6, the height values in the left scale was calculated based on a fixed “standard” reference pressure value equal to 101, 325 Pa. In order to reduce the error due to the use of a fixed reference, we obtained real time atmospheric pressure values from the Internet as described previously (Figs. 2 and 3 and related text) and substituted the “standard” value by a real-time value at each time. The results are shown in Fig. 7 as the height difference between adjacent floors. It can be seen clearly that our height measurement and the ground truth match closely, indicating that our measurement approach using the MEMS barometer sensor chips is highly accurate.

IV. CONCLUSION

In this work, we have shown the feasibility of using a MEMS barometer sensor chip for a blind or visually impaired person to determine the floor where he/she is located in a multistory building. The measurement mechanism and necessary calibration parameters have been described. A hardware evaluation platform has been implemented. Our method has been evaluated in a twelve-story building using laser-measured floor heights as the ground truth. Our results have shown that, by using the real-time atmosphere pressure reference, our cost-effective method is highly accurate.

Acknowledgments

This work was supported in part by National Institutes of Health Grants No. R01CA165255 and U01HL91736.

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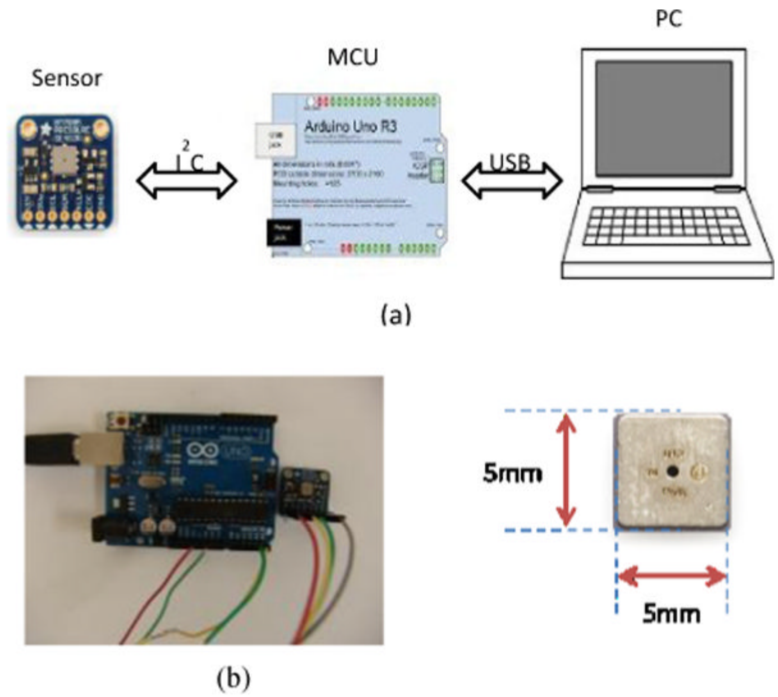

Figure 1.
(a) Block diagram of hardware platform design, (b) Constructed hardware platform, (c) BMP085 barometer sensor chip.

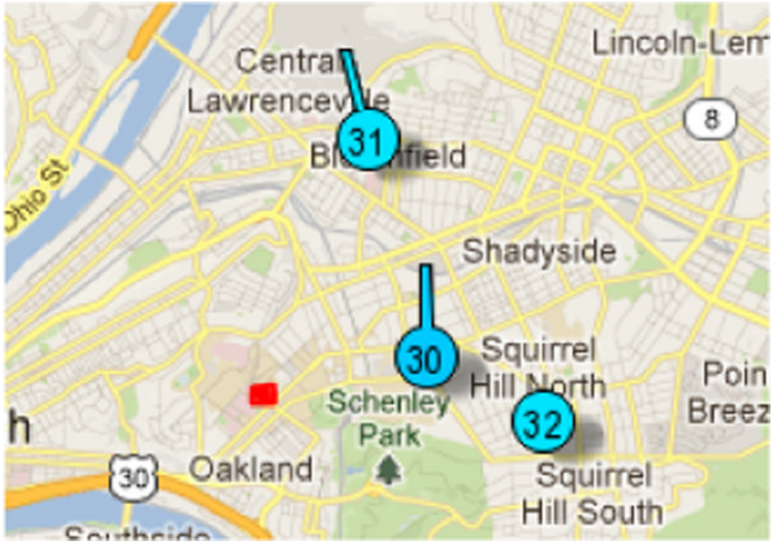

Figure 2.
Geographical locations of three weather stations (blue circles) and a test site (red dot)

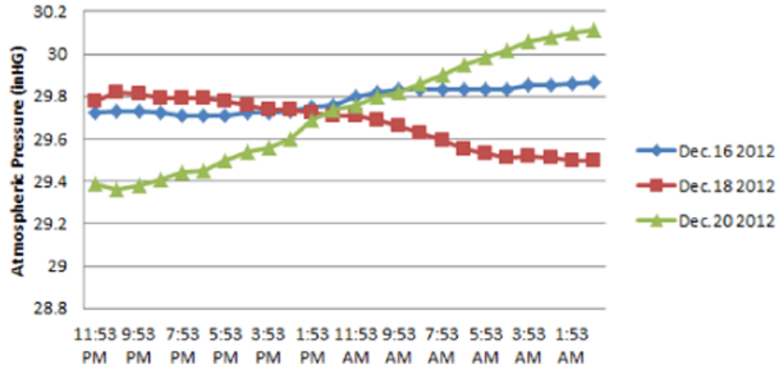

Figure 3.
Atmospheric pressure trends in different days

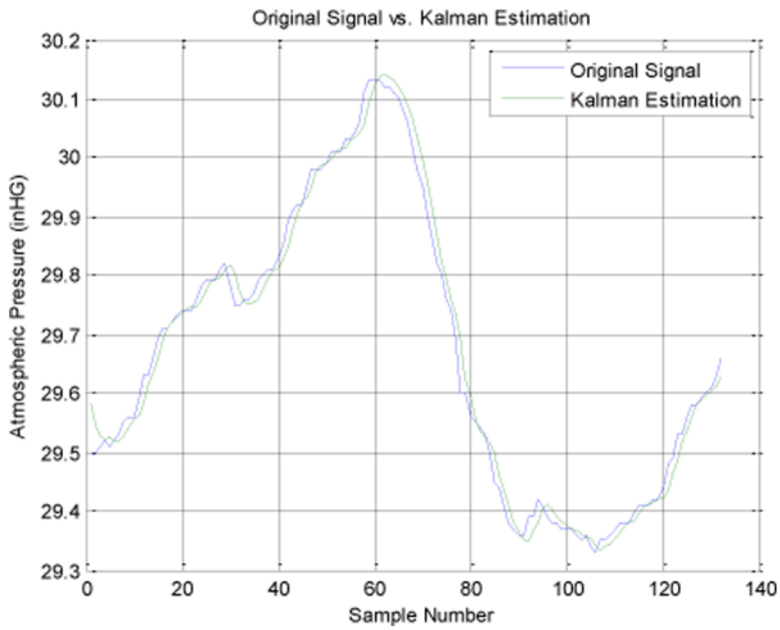

Figure 4.
Atmospheric pressure estimation using a Kalman filter

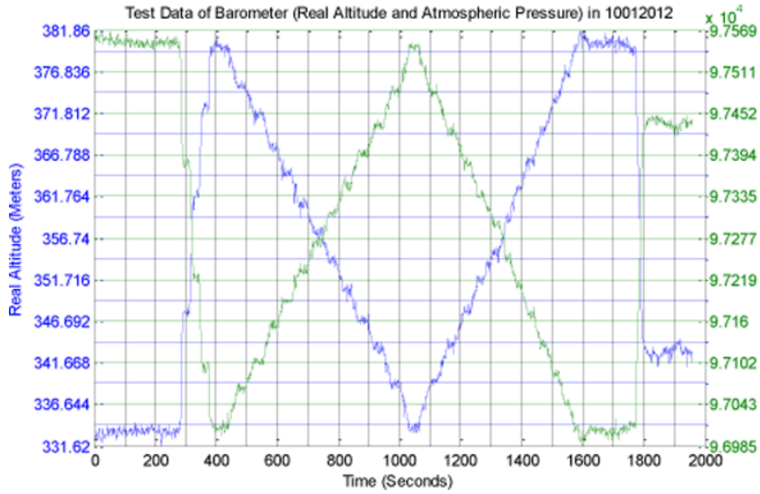

Figure 5.

Atmospheric pressure and height data collected in a multistory building. The subject started from the ground floor. He took the elevator up to the twelfth floor. Then, he took the stairs down to the ground floor and climbed up to twelfth floor again. Finally, he went down to the second floor by elevator.

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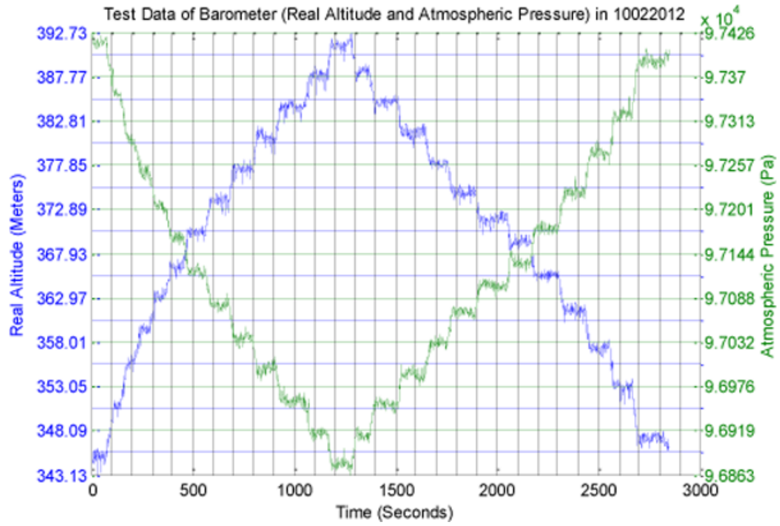

Figure 6.

Atmospheric pressure data collected in a twelve-story building. The subject started from the ground floor. He took the stairs up to the twelfth floor and then went down to the ground floor also by stairs.

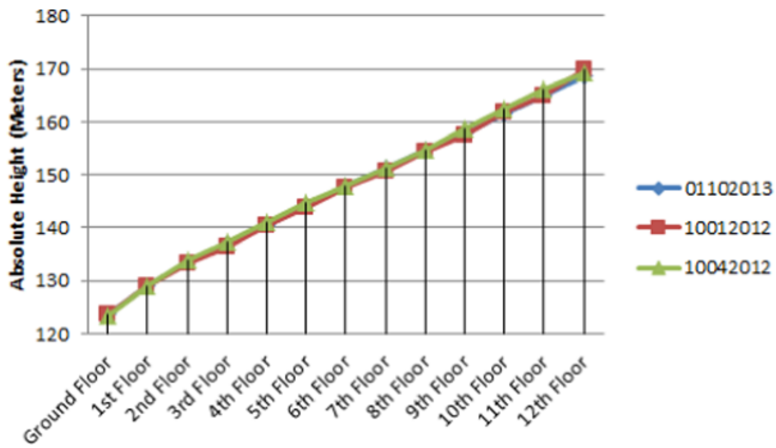

Figure 7.
Modified height information

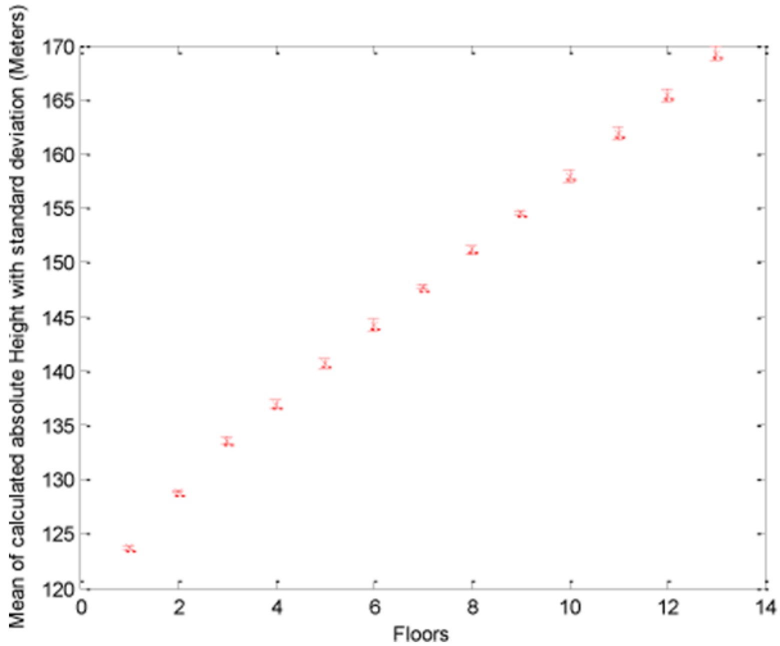

Figure 8.
Mean and standard deviation of calculated altitude values

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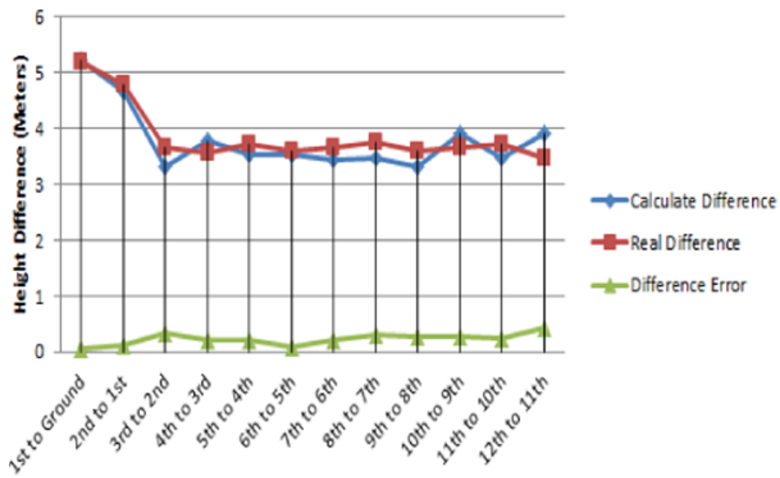

Figure 9.
Comparison of height differences between the barometer-measured values and the ground truth