
User Activity Recognition Method based on Atmospheric Pressure Sensing

Keisuke Komeda

Ritsumeikan University^a

1-1-1 Noji-Higashi

Kusatsu, Shiga 5258577 JAPAN

kome@ubi.cs.ritsumei.ac.jp

Masahiro Mochizuki

Ritsumeikan University

1-1-1 Noji-Higashi

Kusatsu, Shiga 5258577 JAPAN

moma@ubi.cs.ritsumei.ac.jp

Nobuhiko Nishiko

Ritsumeikan University

1-1-1 Noji-Higashi

Kusatsu, Shiga 5258577 JAPAN

nishio@cs.ritsumei.ac.jp

^aHis current affiliation is Mixi, Inc.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from Permissions@acm.org.

UbiComp '14, September 13 - 17 2014, Seattle, WA, USA

Copyright is held by the owner/author(s). Publication rights licensed to ACM. ACM 978-1-4503-3047-3/14/09...\$15.00.

<http://dx.doi.org/10.1145/2638728.2641299>

Abstract

Several studies have been conducted on context recognition as well as hobby and preference extraction by analyzing the data obtained from the sensors in a smartphone. As a smartphone component, a barometer is expected to be useful for activity recognition because of its low power consumption. In this work, we propose an activity recognition method of classifying a user's state into indoor and outdoor states and using a barometer at each state. In the proposed method, the floor of a building on which a user is located is estimated by determining atmospheric pressure variations sensed in the indoor state, and the user's location is estimated by determining atmospheric pressure variations according to the user movement along a track in the outdoor state. In particular, this paper delineates the method of estimating the current floor on which the user is located. We confirmed that it is possible to closely estimate the current floor of the building in the case of user movement among eighteen floors.

Author Keywords

Activity Recognition, Atmospheric Pressure, Floor-level Estimation, Location Estimation, Life-log, GPS

ACM Classification Keywords

I.5.1 [PATTERN RECOGNITION]: Models-Statistical.

General Terms

Experimentation, Management, Measurement, Performance, Reliability

Introduction

Smartphones are equipped with a variety of hardware components such as Wi-Fi, Global Positioning System (GPS), and sensors such as accelerometers and barometers. In the coming years, a smartphone is expected to serve as a mobile sensing platform for collecting a user's activity data in real time using these components. Research activities have been progressing in the field of information extraction by analyzing the data collected from the mobile sensing platform, and applications such as personalized services are foreseen. We have been operating a life-log sensing platform targeting individuals through full-time sensing using the built-in sensors of the mobile sensing platform for recognizing personalized activity.

Barometers have recently been incorporated in mobile sensing platforms. They draw the attention of researchers because they have lower power consumption compared to other smartphone components including GPS, Wi-Fi, and accelerometer, as shown in Table 1. The barometer can measure atmospheric pressure correlated to altitude and climate. Many studies have been focusing on barometers, and the most common approach is to determine atmospheric pressure variations sensed because of a user's vertical movement between floors. This real-time sensed pressure information can be used to recognize the status of the user's movement as well as the current altitude. It is, however, still difficult to exactly identify the floor, which is the basic unit of location recognition in a building. Results of another research[2, 3] show that the moving path of users can be estimated based on the variations in atmospheric pressure according to geographical altitude.

Table 1: Power consumption of each component in operation

Type	%/h
GPS	5.28
Wi-Fi	3.41
Accelerometer	3.64
Barometer	1.79

These research results can be applied to estimate the path taken by the user, but they cannot be used to obtain location information while the user is moving.

In this paper, we propose activity recognition methods based on atmospheric pressure for indoor and outdoor states respectively. We can achieve life-log sensing with lower power consumption by applying the proposed methods to indoor and outdoor states. We apply one method for estimating the current staying floor by extracting information on user movement between floors using atmospheric pressure changes in the indoor state. We apply the other method for estimating the current location by comparing the transition of atmospheric pressure at different locations in the outdoor state. With these estimation results, we can dynamically and effectively switch active sensors. For instance, we will take an approach in which GPS is deactivated while atmospheric pressure sensing, Wi-Fi positioning, and Pedestrian Dead Reckoning (PDR) are activated inside a building until it is recognized that the user is back on the ground floor from where he/she can go outside. Likewise, when it is recognized that the user is outside and on a train moving along a track, we will activate the barometer together with the intermittent use of GPS only when the train stops at each station.

The remainder of the paper is structured as follows. The next section relates our work to other studies. A detailed description of the proposed activity recognition method follows. We present the results of our study, and finally provide the conclusions drawn.

Related Works and Requirements

Related works

It is important to consider the strong relationship between atmospheric pressure and altitude because atmospheric

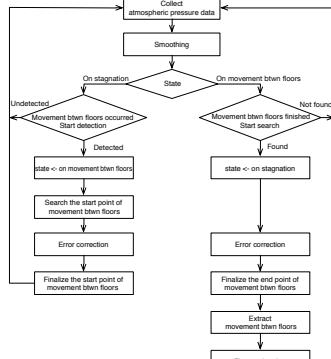
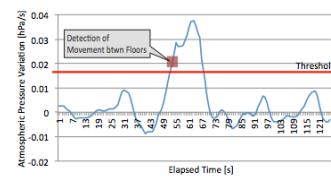
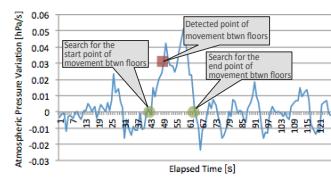


Figure 1: Flowchart of extraction of user movement between floors using atmospheric pressure



(a) Detection of the occurrence of user movement between floors



(b) Search of the start and end points of user movement between floors

Figure 2: Extraction of user movement between floors

pressure varies according to the changes in the altitude of the user's current location. There are several studies such as [5] targeting activity recognition based on data from an atmospheric pressure sensor equipped in recent models of smartphones.

Namiki et al. [4] reported that the major cause of errors in altitude estimation using atmospheric pressure is changes in sea level pressure and sea surface temperature, and proposed an altitude estimation method incorporating a countermeasure against the cause of errors. In their proposed method, errors are corrected by using data from network-connected weather stations and meteorological observatories in Japan. However, their method requires a network-connected weather station close to the place where the altitude estimation is performed, and the correction with data from the meteorological observatories alone provides approximately three meters as the mean value for the estimated altitude error, which is not accurate enough to estimate a user's altitude on a per-floor basis. It is highly likely to provide a wrong floor level because the mean value is almost equivalent to the floor height in an ordinary building.

Researches by Watanabe et al. [7] and Ioroi et al. [1] have a common objective, which is activity recognition in the case of user movement between floors while staying inside a building. They have been focusing on the recognition of movement of users from one floor to another, based on the variations in atmospheric pressure. In these researches, an accelerometer is used in addition to an atmospheric pressure sensor for the recognition of user movement between floors and the estimation of current floor, and there is still room for improvement of these methods in terms of power consumption by fully take advantage of low power consumption of atmospheric pressure sensors. Moreover, their studies targeted at user

activity recognition during a user's movement between floors, not enough at the estimation of the current floor.

Wang et al. [6] proposes a 3D localization scheme that integrates the use of the barometric sensor for altitude estimation, Wi-Fi based 2D localization, and building information. In their scheme, an adaptive self-calibrating algorithm is adopted to recursively detect the floor index by using two filter windows: ahead window and back window. Although their altitude estimation scheme has much in common with ours at an algorithm level, their scheme mainly targets 3D localization in an indoor environment as opposed to our activity recognition method that uses atmospheric pressure sensing for both indoor and outdoor states in order to achieve life-log sensing of user location information with lower power consumption.

As for user activity recognition using atmospheric pressure, user location information is often required besides information on user movements between floors. Morishita et al. [3] have been researching on the tracking of wild animals, and using an approach to estimate the migratory pathway using a GPS receiver and a barometer attached to a wild animal, as well as atmospheric pressure observation stations at fixed locations within a tracking range. By comparing the pressure-altitude history of a tracking target with a digital elevation model, an animal moving-pathway is estimated between distant GPS-positioned points, and lower power consumption is achieved than when using a GPS positioning method alone. In the proposed method, location information for both the start and end points and the measured barometric altitude history are required, and the pathway estimation process needs to be performed from the previous GPS-positioned point after the migration has been completed. The requirement of the fixed stations

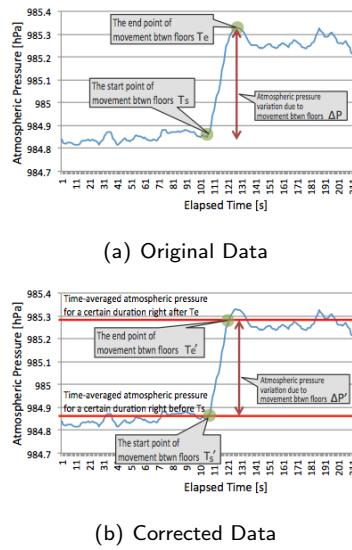


Figure 3: Correction of noise

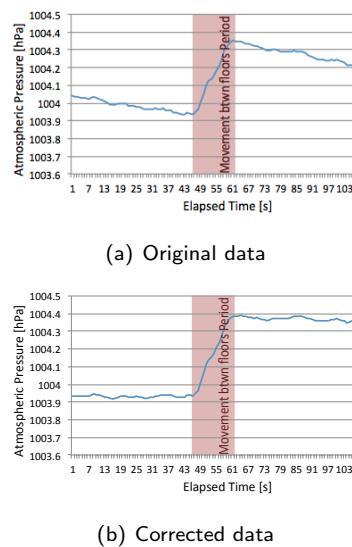


Figure 4: Correction for atmospheric pressure change due

within the migration range increases the installation costs when we apply this method to life-log sensing, because the installation area will be larger depending on the number of people whose activity needs to be recognized. As for the installation cost of fixed stations, Iwanami et al. [2] proposes an alternative method for estimating the path in which a user moves by using only a smartphone besides fixed stations. They attempted to estimate an actual moving path by making an observed atmospheric pressure value at the start point as a reference value, and by observing the transition of atmospheric pressure values relative to the reference point from both the start and end points. These proposed methods, however, have been proposed for the purpose of estimating the path in which the user moves between the start and end points, and are not suitable for the services using location information in real time.

Requirements

The objective of this research is activity recognition using atmospheric pressure sensor with lower power consumption. The essential first step of activity recognition based on atmospheric pressure in the indoor state is the estimation of the floor level, because it enables us to recognize the floor where a user currently stays and we consider it will lead to more advanced indoor activity recognition. Our approach is not based on calculating altitude from an absolute atmospheric pressure value; instead, it is based on reducing relevant values required for recognition as much as possible by focusing on the atmospheric pressure changes and variations because of user movements between floors.

Nevertheless, we require certain values such as the vertical height between floors, current temperature, and atmospheric pressure value at a reference location to accurately estimate the floor level. Our approach obtains

the required values, but the number of values required can be reduced with a certain heuristic such as using knowledge that there are more opportunities of recognizing the revisits to a certain floor by referring to the past life-log than knowing to which floor the user moved among all floors in a high-rise building.

As for the activity recognition based on atmospheric pressure in the outdoor state, it is necessary to estimate location information in real time. User location can be estimated using atmospheric sensor alone, and our method could emerge as one of the methods of obtaining location information with lower power consumption.

Activity Recognition Method

We will introduce here our activity recognition method for extracting information related to the user's movement between the floors of a building and estimating the current floor using atmospheric pressure variations in indoor states.

User movement information extraction and floor-level estimation using atmospheric pressure variation

Atmospheric pressure has correlation with altitude, and therefore atmospheric pressure rapidly changes according to user movements between the floors in indoor states. In the proposed method, we first observe atmospheric pressure variation per unit time, and detect and extract movement information when the variation goes above threshold. Next, we estimate the floor level using atmospheric pressure variations observed when the user moved between the floors. The flowchart shown in Figure 1 illustrates the different steps in the detection of user movement across floors and the floor-level estimation, each of which is explained below.

1. Atmospheric pressure data smoothing

The noise level of an in-built barometer of a mobile sensing platform is high, and therefore the smoothing process of atmospheric pressure data is carried out at each collection. During this process, we prepare two types of data: one is **data for detection** whose noise is substantially eliminated to accurately detect atmospheric pressure changes caused by the user movements between floors, and the other is **data for extraction**, which are smoothed by suppressing the phase delay and blunting of the waveform in order to extract the precise period of user movement between floors.

2. Detection of the occurrence of user movement between floors

It is necessary to extract user movement information per se from atmospheric pressure data in order to eliminate the effect of atmospheric pressure fluctuations due to changes in the climate and to perform floor-level estimation only using atmospheric pressure variations caused by the user movement between floors. As shown in Figure 2(a), the occurrence of user movement between floors is detected when atmospheric pressure variation consecutively goes above threshold for a certain duration. We eliminate false detection due to changes in the climate and atmospheric pressure changes arising from noise by setting atmospheric pressure variation per unit time and consecutive observation period as the conditions of detection.

3. Extraction of user movement information

The detection of the occurrence of user movement between floors occurs some time later from the occurrence of atmospheric pressure change caused by actual floor movement. In the proposed method, we observe atmospheric pressure variation per unit time in the data for extraction, search inflection points before and after the detection of movement, and regard the points respectively

as the start and end points of user movement between floors as shown in Figure 2(b). We finally extract a period from the start point and the end point as user movement information.

4. Correction of extracted movement information

As a result of investigating atmospheric pressure data when movement occurred, we found two main causes of errors in extracting the amount of atmospheric pressure variation at the period of user movement between floors. The causes of errors and the respective correction methods are described here.

Atmospheric pressure change due to changes in climate during user movement between floors

The first cause is the change in atmospheric pressure due to change in the climate. As shown Figure 4(a), an atmospheric pressure change occurs when there are drastic changes in sea level atmospheric pressure and sea surface temperature even if there is no change in altitude. We cannot extract atmospheric pressure variation solely caused by the user's movement between floors under these circumstances. To resolve this problem, we calculate the regression line using atmospheric pressure data for a certain period of time as shown in Figure 4(b), and eliminate the effect of changes in the climate from the data centered around the start point of user movement.

Noise occurrence overlapped with timing before and after the user movement between floors

The second cause is the occurrence of noise in observed atmospheric pressure data. Figure 3(a) indicates the situation where the start and end points of user movement between floors are extracted from the period irrelevant to the likely atmospheric pressure value due to the noise occurrence before and after the movement. To remove the effect of noise, we calculate a likely

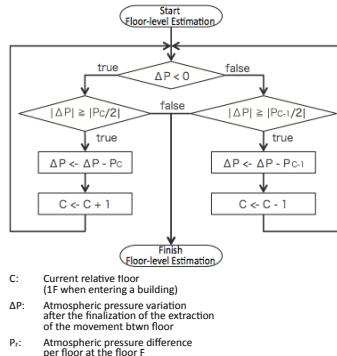


Figure 5: Flowchart of floor-level estimation

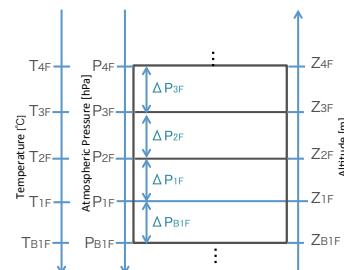


Figure 6: Schematic of reference value calculation

atmospheric pressure value for each floor by averaging data from a certain duration before and after the movement as illustrated in Figure 3(b).

5. Finalization of extracted user movement information

The extracted floor movement is finalized through the process of detection, extraction, and correction.

Timestamps of the start and end points of the user movement between floors as well as the data of atmospheric pressure variations due to the movement are held in the extracted movement information.

6. Estimation of staying floor

We estimate the total number of floors moved as the result of movement between floors by comparing extracted atmospheric pressure variation due to user movement to likely atmospheric variation, which is a **reference value**, between each floor in a building. Figure 5 shows a flowchart of the floor-level estimation process. We can express the current floor as a relative value from an entry point by accumulating the estimated floor level each time a movement between the floors is detected since the user's entry into a building. We proceed to explain how to calculate a reference value in the following paragraph.

Calculation of a reference value

In addition to the atmospheric pressure variation due to user movement between floors, we need to know atmospheric pressure difference between floors while the user stays in a building; in other words, a reference value is required as a correct answer for the floor-level estimation. We adopt an approach to calculate a reference value tailored to each floor because in some cases, the distance between different floors varies. As shown in Figure 6, we can calculate the atmospheric pressure difference between

each floor as a reference value from the atmospheric pressure at each floor. Atmospheric pressure P_F at each floor F can be calculated from the sea-level atmospheric pressure P_0 , temperature at each floor T_F , and altitude at each floor Z_F as shown in Eq. (1):

$$P_F = P_0 \left(1 - \frac{0.0065Z_F}{T_F + 0.0065Z_F + 273.15}\right)^{5.257} \quad (1)$$

As the sea-level atmospheric pressure and the station's temperature change from time to time, we can calculate a more accurate reference value using parameters close to those measured in the actual environment. We obtain these parameters from three data sources: (i) International Standard Atmosphere (ISA), (ii) observed values at the mobile sensing platform, and (iii) data from the meteorological observatory. Table 2 summarizes the parameters obtained from each data source. We can calculate the sea-level atmospheric pressure P_0 and temperature T_F at each floor from obtained data accordingly using Eqs. (2)-(4). Note that L denotes the temperature lapse rate, and it takes the value -0.0065 K/m in an environment where the altitude is less than or equal to 11 km.

$$P_0 = \frac{P_F}{\left(1 - \frac{0.0065Z_F}{T_F + 0.0065Z_F + 273.15}\right)^{5.257}} \quad (2)$$

$$T_0 = T - LZ \quad (3)$$

$$T_F = T_0 + LZ_F \quad (4)$$

Moreover, a temperature sensor built into a mobile sensing platform generally measures the internal temperature of a device and not the air temperature; therefore, we consider that the temperature conforms to ISA. We calculate the atmospheric pressure difference

Table 2: Parameters obtained from each data source

Data source	Obtained parameters
(i)	Sea-level atmospheric pressure P_0 : 1013.25 hPa, Sea surface temperature T_0 : 288.15 K
(ii)	Station's atmospheric pressure P
(iii)	Sea-level atmospheric pressure P_0 , Station's temperature T (updating every hour on the hour)

Table 3: Building environment

Building	Each floor's height	Ground height
Research Building (CC)	4.0 m for floor 1–2 4.3 m for floor 3–7	154.2 m
Osaka Fukoku Seimei Building (FS)	5.9 m for floor 1 4.9 m for floor 2–6 4.1 m for floor 7–14 4.2 m for floor 15–19	0.4 m

between each floor, ΔP_F , which is a reference value, by taking a difference between atmospheric pressure value calculated at each floor, that is, $P_{F+1} - P_F$.

Evaluation

In this section, we evaluate the method used to estimate the floor level on which the user is located.

Evaluation of floor-level estimation

Evaluation of correction effect

Here, we evaluate the correction method. Information regarding user movement between floors with/without correction is extracted from the data collected in advance, and we confirm the effect of the correction by comparing the difference from a reference value. We collected data when the user moved from one floor to another in a building using stairs, and the difference in the altitudes of the floors is 4 m. We prepared test environments with two conditions: when the atmospheric pressure fluctuation caused by change in climate is considerable, and when the fluctuation is negligible. We conducted experiments on the user movement between floors four times in each environment. Figure 8 shows the results with/without data correction. Figure 8(a) shows the result of a trial with a large atmospheric fluctuation, and we confirmed that the difference with a reference value largely decreased before and after the correction. Figure 8(b) expresses the result of a trial with a small atmospheric fluctuation, and it can be observed that the difference before and after the correction is small because there is little room for the correction.

Although the maximum values after correction were larger than those before correction in the experiments, the differences were smaller overall, and the fact does not affect the floor-level estimation process. For floor-level estimation using the proposed method, we can tolerate an

error up to approximately 0.24 hPa in the test environment.

Evaluation of errors in floor-level estimation on the extraction of floor movement

As for the evaluation of the floor-level estimation method, we confirmed the accuracy of the floor movement extraction and the floor-level estimation by comparing the difference between atmospheric pressure variation of an extracted floor movement, **an extracted value**, and a reference value at the correct floor visited. Moreover, we performed an evaluation on data sources used for the calculation of reference values by comparing actual reference values calculated with each data source. Measurements were performed with three patterns of floor movement, and the difference between extracted atmospheric pressure variation and a reference value is presented. Table 3 summarizes the environment variables of the buildings where experiments were performed, and the details of each trial pattern are given in Table 4.

Table 4: Details of each trial

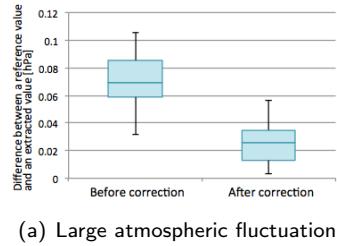
Type of trial	Building	# of floors moved	# of trials
By time period	CC	+1 floor	8 for each
By total # of floors moved	CC	+1 – +6 floors	6 for each
Large # of floors moved	FS	+18 floors	3

Floor-level estimation by time period

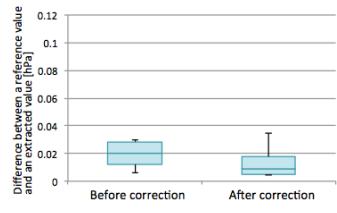
Figure 10 shows the result of trials to confirm that estimating the floor level of the building where the user is located is possible regardless of the period of time.

Floor-level estimation by the number of floors moved

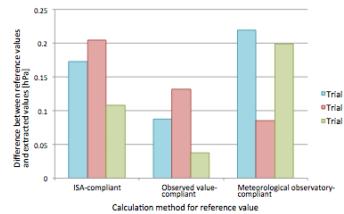
We evaluated the feasibility of the floor-level estimation as well as the effect on the accuracy of the estimation of user



(a) Large atmospheric fluctuation



(b) Small atmospheric fluctuation

Figure 8: The effect of correction**Figure 9:** The difference between the extracted value and a reference value (large number of floors moved)

movement between floors by changing the total number of floors moved. Figure 7 illustrates the result of the evaluation by each number of floors moved and by each reference value.

Floor-level estimation with a large number of floors moved

We also evaluated the feasibility of the floor-level estimation along with the effect on the accuracy in the case of user movement with the large number of floors moved. The objective of this evaluation is to confirm the accuracy of the floor-level estimation with each reference value through the trials of user movement between floors where the accumulation of the difference between extracted values and reference values becomes large.

Figure 9 shows the results for each of the three reference value calculation methods employed.

The extracted values and reference values fall within an allowable error of nearly 0.24 hPa in every case, where the maximum number of floors moved is 18 floors, and we confirmed that the floor-level is correctly estimated. We also confirmed that the difference becomes large when the total number of floors moved increases, especially in the case of meteorological observatory-compliant reference values. This is because the temperature observed by the meteorological observatory would be different from room temperature inside a building where air conditioning is used, and errors arising from atmospheric pressure variations are accumulated as the number of floors moved increases. In the case of floor-level estimation with the large number of floors moved, where errors obviously appear, the estimation using observed-value-compliant reference values produced the best results. It seems that this is because air temperature in an indoor environment is close to that of the ISA model, and atmospheric

pressure observed by a mobile device enables to apply the sea-level atmospheric pressure, which is close to that of the actual building environment. From these results, we presume that the calculation of observed data-compliant reference values is suitable for floor-level estimation in an indoor environment.

Figure 11 shows the estimation of error increase depending on the changes in altitude caused by the user's movement between floors when using observed-value-compliant reference values. The linear formula for the estimated maximum error is expressed with a gradient, which is the increase in the median of errors according to the increase in the number of floors moved observed from the results of trials, and y-intercept, which is the difference between the observed maximum error value and the median.

**Figure 11:** Estimated maximum error

Based on the experimental result shown in Figure 11, we obtained a prospect for performing floor-level estimation at a time up to 53 floors, which corresponds approximately to 212 m height, in condition that the height per floor of a building is 4 m, where allowable error is nearly 0.24 hPa. The number of buildings whose height

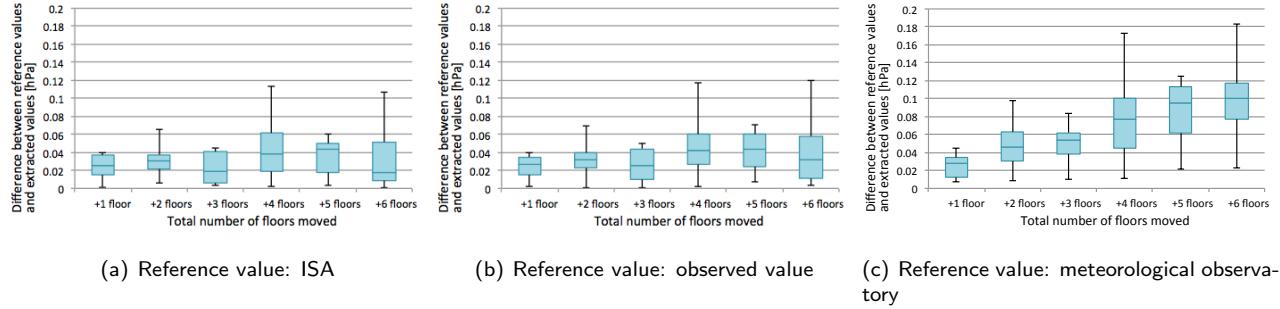


Figure 7: The difference between extracted values and reference values (by total number of floors moved)

Table 5: Staying time at a stair landing and the recognition rate of each movement between floors

Staying time in seconds at a stair landing	Recognition rate of movement between floors
9	100%
8	90%
7	80%
6	70%
5	40%
4	0%

exceeds 200 m is limited in Japan, and we think our method is applicable to floor-level estimation for the majority of buildings. Moreover, because the performance of floor-level estimation is strongly affected by the precision of the barometer, more precise estimation is expected to be possible using our method if the performance of the sensor is improved.

Evaluation of the granularity of user movement recognition
In the proposed method, user movement between floors is recognized by observing the atmospheric pressure variation per unit time, and whose change points from positive to negative and vice versa are used for the extraction of endpoints of user movement between floors as well. As the waveforms of atmospheric pressure data are smoothed, it can be recognized as one user movement between floors even if it consists of multiple user movements between floors from a fine-grained perspective. We performed the user movement between floors using stairs, and verified the time required to recognize each movement with the proposed method by changing the staying time at the landings of stairs. It was found that a movement between floors can be recognized

as a separated ones if the staying time is more than nine seconds from the results in Table 5. If we can observe the occurrence of stair landings in the time series of user movement between floors, it will be useful as a reinforcement for indoor location positioning under the condition that the building structure is known in advance.

Conclusion

In this paper, we proposed an indoor-stay recognition method using the estimation of user movement between floors in an indoor state, along with a current location estimation method by comparing the transition of atmospheric pressure in moving along a track in an outdoor state, and detailed the former method. We focused on that the sudden changes in atmospheric pressure sensed in the indoor state because of the user's movement between the floors, and proposed a current floor-level estimation method by observing atmospheric pressure values. We confirmed that the current floor-level is correctly estimated even if the total number of floors is as high as 18. Future work will include performance measurements of the floor-level estimation method in adverse environmental conditions.

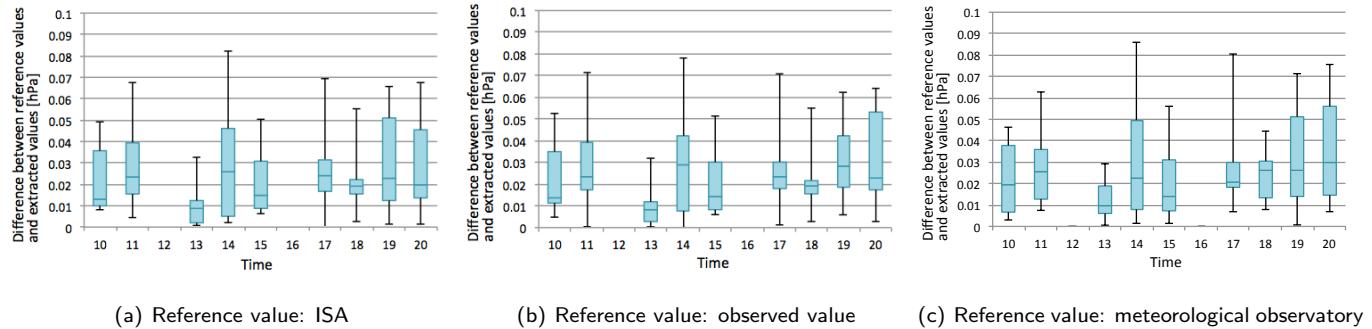


Figure 10: The difference between extracted values and reference values (by time period)

Acknowledgements

Part of this research is supported by SCOPE (#132307011) (Strategic Information and Communications R&D Promotion Program) from the Ministry of Internal Affairs and Communications(MIC), Japan.

References

- [1] Irori, S., Suzuki, T., and Tanaka, H. Multiple floor dead reckoning using a smartphone built-in sensors. *Multimedia, Distributed, Cooperative, and Mobile Symposium (DICOMO2013)* (Jul 2013), 723–735.
- [2] Iwanami, K., and Arai, I. Proposal and evaluation of a method for estimating a moving path using air pressure sensor values and digital elevation model. *IPSJ SIG Technical Report, UBI 2013*, 46 (Mar 2013), 1–7.
- [3] Morishita, K., and Mita, N. Migratory pathway estimation based on pressure altitude history. *Journal of the Institute of Positioning, Navigation and Timing of Japan* 4, 1 (2013), 1–10.
- [4] Namiki, W., Ichino, M., Kasahara, H., Yoshii, H., and Yoshiura, H. Location estimation using smartphone's sensor. *Multimedia, Distributed, Cooperative, and Mobile Symposium (DICOMO2013)* (Jul 2013), 1133–1139.
- [5] Sagawa, K., Ishihara, T., Ina, A., and Inooka, H. Classification of human moving patterns using air pressure and acceleration. In *Industrial Electronics Society, 1998. IECON '98. Proceedings of the 24th Annual Conference of the IEEE*, vol. 2 (Aug 1998), 1214–1219 vol.2.
- [6] Wang, H., Lenz, H., Szabo, A., Hanebeck, U. D., and Bamberger, J. Fusion of barometric sensors, wlan signals and building information for 3-d indoor/campus localization. In *In proceedings of International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI 2006)*, 5 (2006), 426–432.
- [7] Watanabe, T., Kamisaka, D., Muramatsu, S., Kobayashi, A., and Yokoyama, H. Locomotion estimation method using pressure sensor. *IEICE Technical Report, Mobile Multimedia Communications (MoMuC)* 111, 296 (Nov 2011), 19–23.