Altitude Determination of a Pedestrian in a Multi-storey Building

Günther Retscher

Institute of Geodesy and Geophysics, Vienna University of Technology,
Gusshausstrasse 27-29, A – 1040 Wien, Austria, gretsch@pop.tuwien.ac.at

Abstract

A challenging task in using pedestrian navigation and guidance services indoors is to determine the correct floor of a user in a multi-storey building because most indoor location techniques only provide 2-D information. In this case it can be recommended to augment the position determination system with a barometric pressure sensor for direct observation of height differences. In the research project NAVIO (Pedestrian **Nav**igation Systems in Combined **I**ndoor/**O**utdoor Environments) tests with different sensors have been performed and their results are presented. The tests show that it is possible to determine the correct floor of a user using a barometric pressure sensor as the standard deviation of the estimation of the height differences is better than ± 1 m.

1 Introduction

In recent years new technologies and methods for positioning in indoor environments have been developed. Useable geolocation techniques include cellular phone positioning, the use of WiFi or WLAN (wireless local area networks), UWB (ultra-wide band), RFID (radio frequency identification), Bluetooth and other systems using infrared, ultrasonic and radio signals (see e.g., Retscher, 2005b). In this chapter a brief overview of some of these technologies that can be employed for personal navigation systems is given. Most of the systems, however, are able to locate the user only in two dimensions and the altitude (or height) of the user is not determined. Then the height has to be observed using an additional sensor to be able to locate a user on the correct floor of a multi-storey building. In the research project NAVIO (Gartner, et.al., 2004) at our University the use of a barometric pressure sensor for the direct observation of height differences is suggested. Test measurements performed in our 5-storey office building are presented.

2 Overview of indoor location systems

For indoor positioning different location techniques have been developed which use signals such as infra red, ultra sonic, radio signals or visible light (Retscher and Kistenich, 2006). Methods for position determination include Cell of Origin (CoO) where the location of the user is described in a certain cell area around the transmitter, Time of Arrival (ToA) where the travel time of a signal between a transmitter and receiver is obtained, Time Difference of Arrival (TDoA) where the time difference of signals sent from a transmitter is determined at two receiving stations, signal strength measurement for location determination using fingerprinting (e.g. WiFi or WLAN fingerprint, see Retscher, 2004) where the signal strength values are compared with previous stored values in a database and the location of the user is obtained using a matching approach, and location determination using digital images (Retscher and Kistenich, 2006). Table 1 gives an overview about different indoor location techniques.

The systems Active Badge (Want et al., 1992) and WIPS (Roth, 2004) employ infra red signals for location determination, Active Bat (Hightower und Boriello, 2001) and Cricket (Roth, 2004) use ultra sonic signals. For the location of cellular phones ToA or TDoA measurements can be performed (Retscher, 2002). Satellite or similar signals are also employed for the location of cellular phones using Assisted GPS (A-GPS) or for the Australian system Locata (Barnes et al., 2003) which makes use of standard RTK positioning with GPS similar signals. For indoor positioning the use of WiFi or WLAN (Wireless Local Area Networks) has become popular and the systems Radar (Bahl and Padmanabhan, 2000), IMST ipos (Imst, 2004), Ekahau (Ekahau, 2005) and WhereNet (WhereNet, 2005) are examples. Apart from WiFi also Ultra Wide Band (UWB) signals and Bluetooth (Hallberg et al., 2003) can be employed. SpotON employs also

Table 1. Comparison of indoor location techniques

System name	Signal	Method	Absolute Positioning	Relative Positioning	Positioning	Tracking	Geometrical	Symbolic	Costs	Positioning Accuracy [m]
Active Badge	IR	CoO	✓			✓		✓	low	room
WIPS	IR	CoO	✓		✓			✓	low	room
Active Bat	US	ToA	✓			✓	✓		low	0,1
Cricket	US	ToA	✓	✓	✓			✓	low	1,2
GSM	RS	TDoA AoA	✓			✓	✓		low	50-100
A-GPS	RS	ToA	✓		✓		✓		high	20-25
Locata	RS	ToA	✓		✓		✓		high	0,1-1
Radar	RS	SS	✓		✓	✓	✓		high	3-4
IMST ipos	RS	SS	✓			✓	✓		high	1-3
Ekahau	RS	SS	✓		N/A	N/A	✓		high	1-3
WhereNet	RS	SS	✓		N/A	N/A	✓		N/A	N/A
UWB	RS	ToA TDoA	✓		✓		✓		high	0,2
Bluetooth	RS	CoO	✓		✓	✓	✓		average	10
SpotON	RS	SS	✓	✓	✓	✓	✓		average	1 m^3
RFID	RS	CoO		✓		✓		✓	low	1-20
CyberCode	VL	DI		✓	✓			✓	average	variable
Ubitrack	VL	DI		✓		✓	✓		N/A	N/A
EasyLiving	VL	DI	✓			✓	✓		high	variable

The following abbreviations are used in Tabel 1:

Signals:
IR.......Infra red
US......Ultra sonic
RS......Radio signals

Postioning Methods:
CoO.... Cell of Origin
ToA.... Time of Arrival
TDoA.. Time Difference of Arrival

VL......Visible light
N/A.....not available
AoA.... Angle of Arrival
SS…... Signal strenght measurement
DI…… Digital images

radio signals and performs signal strength measurements (Hightower et al., 2000). Table 1 also contains three systems using digital images for location determination, i.e., CyberCode (Rekimoto et al., 2000), Ubitrack (Newman et al., 2004) and EasyLiving (Brumitt et al., 2000).

For navigation and way finding in smart environments the use of RFID (Radio Frequency Identification) for ubiquitous positioning is also a promising solution. RFID is a method of remotely storing and retrieving data using devices called RFID tags. An RFID tag is a small object, such as an adhesive sticker, that can be attached to or incorporated into a product. RFID tags contain antennas to enable them to receive and respond to radio-frequency queries from a RFID transceiver. For location determination RFID tags can be placed on active landmarks or on known locations in the surrounding environment. If the user passes by with a RFID reader, the tag ID and additional information (e.g. the 3-D coordinates of the tag) are retrieved. Thereby the range between the tag and reader in which a connection between the two devices can be established depends on the type of tag. RFID tags can be either active or passive. Passive RFID tags do not have their own power supply and the read range is less than for active tags. They have practical read ranges that vary from about 10 mm up to about 5 m. Active RFID tags, on the other hand, must have a power source, and may have longer ranges and larger memories than passive tags, as well as the ability to store additional information sent by the transceiver. At present, the smallest active tags are about the size of a coin. Many active tags have practical ranges of tens of metres, and a battery life of up to several years. The location method is Cell of Origin (CoO) and the size of the cell is defined by the range of the tags. Therefore using active RFID tags the positioning accuracy ranges between a few metres up to tens of metres and with passive tags up to about 5 m. Although this positioning accuracy can be low for some applications, RFID positioning can be very useful in combination with other sensors.

3 Altitude determination of a pedestrian using a barometric pressure sensor

In the research project NAVIO the Vaisala pressure sensor PTB220A (Vaisala, 2005) is employed for the determination of height differences from changes of the air pressure. The PTB220A is designed for measurements in a wide environmental pressure and temperature range with an extremely high accuracy. Starting from a given height the pressure changes can be converted in changes in height using the following equation:

$$\Delta H = H_2 - H_1 = 18464 \cdot \left(1 + 0{,}0037 \cdot t_m\right) \cdot \left(\lg B_1 - \lg B_2\right)$$

where ΔH is the height difference between two stations 1 and 2, B_1 and B_2 are the pressure observations at station 1 and 2 and t_m is the mean value of the temperature of both stations. It must be noted that this equation is an approximation formula that is valid for central Europe only (Kahmen, 1997). Tests showed that there is no significant difference between the results using the approximation formula and an equation derived from Jordan which is also valid for other parts in the world and takes into account the geographic location of the two stations.

4 Sensor tests: locating the user on the correct floor in a multi-storey building

Substantial sensor testing has shown that we are able to determine the correct floor of a user in a multi-storey building using this sensor. First of all the drift of the sensor was analyzed in several long term tests. Then it was investigated, if a functional connection between the observed pressure differences and the height differences can be derived. This connection can be described using characteristic curves. Finally the accuracy of the height determination was analyzed in detail.

Figure 1 shows the test area which is in our office building at the Vienna University of Technology. The trajectory leads from the main entrance of the building via two staircases to our institute which is located on the third floor of the 5-storey building.

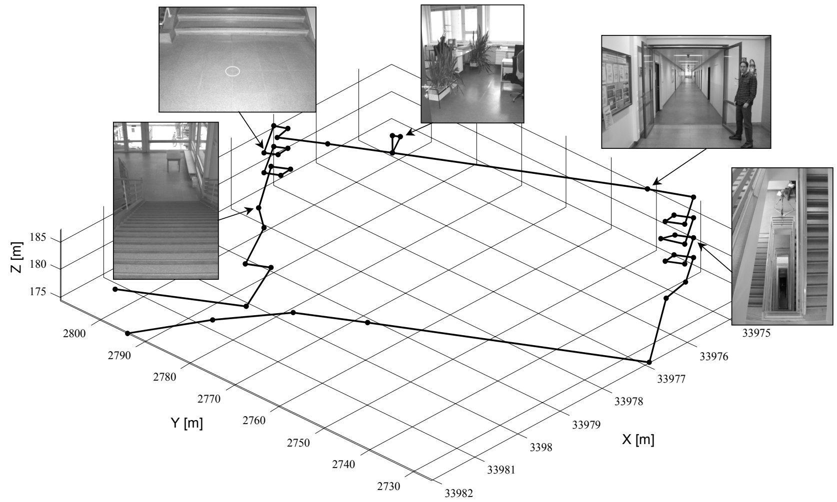

Fig. 1. Indoor trajectory in our office building at the Vienna University of Technology from the main entrance onwards to our institute located on the third floor of the building

5 Determinations of the sensor drift

Figure 2 shows an observation of the sensor over two hours performed on a benchmark located on the roof of our building. The height of the benchmark is 200.05 m. The sampling rate of the observations was one second. During the two hour observation period the temperature dropped from 16.5° C to 15.8° C. The maximum deviations from the given height reach values of + 0.42 m and – 0.64 m in the first half hour. Thereby the observations can vary randomly in this range of about 1.06 m. Some discontinuous variations are also caused by the wind during the observation period. In summary, it can be concluded that no significant drift rates could be seen during several long term tests. The influence of wind, temperature changes and the air conditioning system inside the building, however, affects the results and can be clearly seen in the observations. For the first half hour of operation variations of the air pressure in the range of ± 0.15 hPa could be seen. Considering the resolution of the sensor which is 0.01 hPa, the sensor can be regarded as stable and no drift rate will be considered in the following.

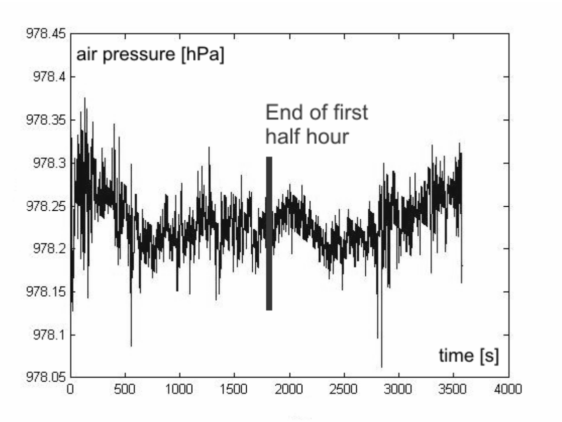

Fig. 2. Long term sensor observations with the Vaisala pressure sensor PTB220A on benchmark No. 11 on the roof of our building

6 Determination of a characteristic curve for the barometric pressure sensor

A characteristic curve shows a functional connection between the observed pressure differences and the height differences. If such a curve exists and the functional connection is linear, then the pressure differences can be converted into height differences. For this purpose observations in the building have been carried out during different times of the day. Figure 3 shows six observations in the morning of one day and the resulting linear characteristic curve. The start point of three of these observations was on the ground floor and for the other three on the roof of the building. The characteristic curve is given by the following equation:

$$\Delta h = 8.769 \cdot \Delta p$$

where Δh is the height difference and where Δp is the difference in air pressure.

As can be seen in Figure 3, the measurement series show a good agreement with the resulting characteristic curve. There is also no difference, if the observations begin either on the ground floor or on the roof of the building. Further characteristic curves have been obtained from different measurement series and can be found in Retscher & Kistenich (2005). As a result it can be seen that we are able to calculate a linear characteristic curve which describes a linear functional connection between the air pressure observations and the changes in height.

7 Determination of the height in the building

Figure 4 shows observations with the Vaisala pressure sensor PTB220A in our office building starting from the main entrance up to the third floor of the building where our institute is located. It can be clearly seen that the sensor is able to determine the correct floor of the user with a high precision. The standard deviation of the pressure observation is in the range of ± 0.2 hPa and the maximum deviation of the determined height is less than ± 1 m for 91 % of the observations. Thereby the deviations depend also on the time of day; higher deviations are obtained during noon where usually more people are inside the building and higher variations of the air pressure occur caused by higher air circulation due to frequent opening of doors and windows. The maximum outlier during noon reaches values of about 1.4 m. In summary, it can be concluded that the sensor is able to locate the user on the correct floor.

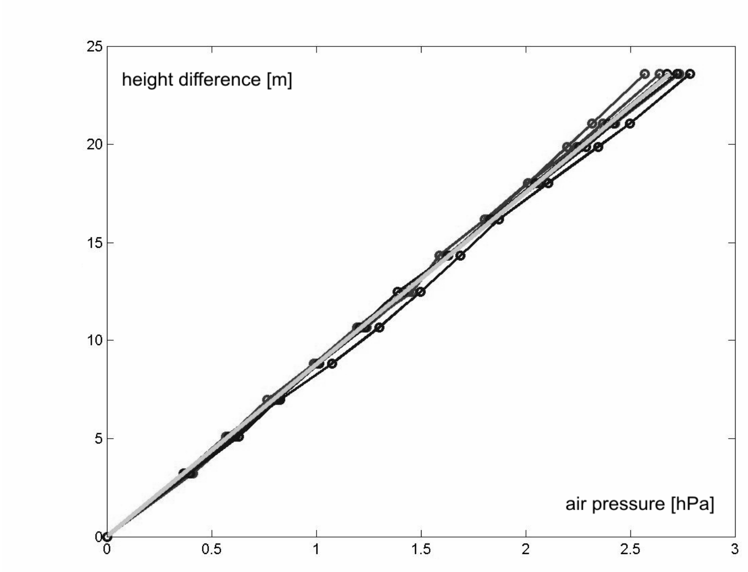

Fig. 3. Linear characteristic curve of six observations in our office building between the ground floor and the roof (6th floor)

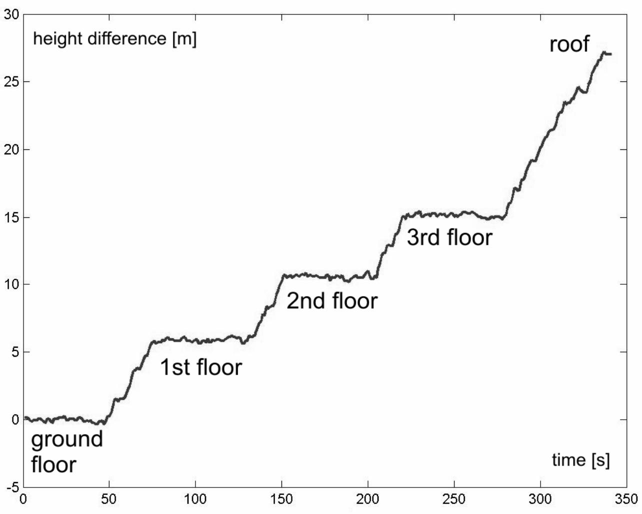

Fig. 4. Test measurements with the Vaisala pressure sensor PTB220A in our office building at the Vienna University of Technology

8 Concluding remarks and outlook

A variety of systems have been developed in recent years to determine the location of people and objects within building. This chapter has provided an overview about their operation and performance. They provide mostly only 2-D location determination of the user and the determination of the correct floor is a very challenging task. Therefore, in the research project NAVIO, the use of a barometric pressure sensor for direct observations of the altitude is investigated. It be can seen from the presented sensor tests that the elevation of a pedestrian within a building can be determined with high precision and reliability if a barometric pressure sensor is employed. Then, in combination with other indoor location techniques and dead reckoning sensors, a continuous 3-D position determination in indoor environments is possible. Recently an indoor location system based on WiFi fingerprinting has been installed in our office building and we are working on its integration in our multi-sensor system. Using the WiFi system it is possible to locate the user in two dimensions with a positioning accuracy in the range of 1 to 3 m. The system has been tested in a study and the interested reader is referred to (Retscher et al., 2006).

In our multi-sensor approach the observations of all sensors have to be combined and an integrated position solution has to be obtained. For the integration of all observations a multi-sensor fusion model based on an extended Kalman filter which makes use of a knowledge-based pre-processing of the sensor observations shall be applied. The principle of this approach is presented in Retscher (2005a). The fusion model consists of two steps, i.e., a knowledge-based pre-processing filter followed by a central Kalman filter for optimal estimation of the current user's 3-D position. The knowledge-based pre-processing filter represents an extension of common multi-sensor fusion models in a way that the data based system analysis and modelling is supplemented by a knowledge-based component and therefore not directly quantifiable information is implemented through formulation and application of rules. These rules are tested in the pre-processing step and if they are fulfilled certain actions are executed. Due to the knowledge-based analysis of the sensor observations gross errors and outliers can be detected and eliminated in this processing step. In addition, the pre-processing filter supplies input values for the stochastic model of the central Kalman filter. Therefore, the weightings of the sensor observations can be adjusted in the Kalman filter depending on the availability and quality of the current observations. This integration approach will be implemented and further sensor tests will be carried out to test and analyze this approach. Due to the development of new advanced sensors it can be expected that multi-sensor solutions which provide location capabilities in outdoor and indoor environments will be deployed in pedestrian's navigation services in the near future. We believe that these services will play an important role in the field of location-based services.

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