# PEDESTRIAN NAVIGATION SYSTEMS AND LOCATION-BASED SERVICES

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## Abstract

Pedestrians have often ways in unfamiliar urban environment or in complex buildings. In these cases they need guidance to reach their desired destination, for example a specific room in a local authorities' building, a counter, or a department at an university. The goal of location-based mobile services is to provide such guidance on demand (anywhere, anytime), individually tailored to the actual information needs and presented in preferred forms. Thereby the navigation service requires positioning and tracking capabilities of a mobile user with a certain positioning accuracy and reliability. Especially navigating in urban areas is a very challenging task as pedestrians move in spaces where no one of the known positioning techniques works continuously in standalone mode and the movement is in a much more complex space than 2-D networks (i.e., on pedestrian paths and along roads, outdoor and indoor, through underground passages, etc.). To solve this challenging task of continuous position determination, a combination of different location technologies is required. The integration of the sensors should be performed in a way that all the sensors are tightly coupled in the sense of a so-called multi-sensor system. In a new research projet on our University entitled "Pedestrian Navigation Systems in Combined Indoor/Outdoor Environements (NAVIO)" we are working on the improvement of such navigation services. We believe that these services will play an important role in the field of location-based services in the near future as a rapid development has already started which is driven by their possible applications. The project is mainly focusing on the information aspect of location-based services, i.e., on the user's task at hand and the support of the user's decisions by information provided by such a service. Specifications will allow to select appropriate sensor data and to integrate data when and where needed, to propose context-dependent routes fitting to partly conflicting interests and goals as well as to select appropriate communication methods in terms of supporting the user guiding by various multimedia cartography forms. To test and to demonstrate our approach and results, the project takes a use case scenario into account, i.e., the guidance of visitors to departments of the Vienna University of Techology. First results of our project will be presented in this paper.

## 1 Introduction and Motivation

Starting from the development of common vehicle navigation systems, nowadays modern and advanced location sensors are available on the market which can be employed in navigation systems for pedestrians. In this paper, suitable sensors and location techniques which can perform continuous position determination for pedestrians are introduced and presented. The aim of our development is a navigation system design for pedestrians that will enable the most precise estimation of the position in real-time using simple low-cost sensors. Following an analysis of existing navigation systems and location-based services (LBS), location sensors will be classified and the most adequate ones for different tasks will be selected. The integration of these sensors is performed using a multi-sensor fusion model based on a Kalman filter approach. Practical test have shown that a multi-sensor system can achiev a high level of performance for the navigation and guidance of a pedestrian in urban and mixed indoor/outdoor environments.

## 2 Applications of Pedestrian Navigation Systems and Location-based Services

Navigation and guidance services are employed for different tasks. Thereby we have to make a distinction if the service is only used to determine the current position of the user for a location dependant enquiry in a location-based service (LBS) or if a navigation and guidance of the user from a given location to a certain destination has to be performed. In general, a wide range of applications is possible that can be characterized in:

- Applications using cellular phones (e.g. location determination of an emergency call, report of car breakdowns, location of persons),
- Location-based services (e.g. enquiry and download of location dependant information, tourist guides, hiking guides),
- Navigation of handicapped or blind persons,
- Applications for public institutions (e.g. guidance of emergency vehicles of police, fire-brigade and rescue service).

In this cases, navigation systems usually employ satellite positioning systems and sometimes additional sensors (e.g. dead reckoning) for location determination. Location determination using mobile phones is performed in systems where only low accuracy requirements for the position determination are necessary. Most location based services employ cellular or wireless phone location techniques.

Table 1 shows a survey (that does not make any claim on completeness) of typical examples for navigation systems and location-based services and their employed location technique. In this overview, systems and services have been grouped into three different areas, i.e., cellular phone applications, location-based services and systems for handicapped persons. In general, it can be said that services which use only location determination with cellular phone positioning [see e.g. 5, 9, 20] do not require a high positioning accuracy. One exception is the tourist guide for the city of Vienna, i.e., the service Lol@ [13], that employs also manual input of the street address of the current user's position. For higher positioning accuracies, however, in the systems mainly satellite positioning (GNSS) is employed. To bridge outages in satellite positioning, some navigation systems for handicapped persons use also other sensors which are able to determine the current position of the user starting from a given location with measurements of the direction of motion (orientation or heading) and the travelled distance. This location technique is also referred to as Dead Reckoning (DR) and the sensors are called DR sensors (i.e., a pedometer or accelerometers for travel distance measurement, a compass and gyro to obtain the direction of motion of the user). Main disadvantages are that the location determination in buildings as well as the determination of the height of the user (e.g. for determination of the correct floor in a multi-storey building) is neglected by the systems described in Table 1. The cellular phone is used, in general, for data communication to provide location dependant information from databases in location-based services [21].

## 3 Suitable sensors and location techniques for pedestrian navigation systems

Suitable sensors and location techniques for pedestrian navigation have been identified in our project and their observables and accuracies are summarized in Table 2.

| Application / System | | General criterion | | | | Positioning Sensors | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Navigation | GIS / Data base | Cellular phone for data exchange | Compass for orientation | GNSS | Indoor positioning system | Cellular phone positioning | Dead reckoning (DR) | Compass for DR | Map matching | Acceleration sensors |
| Cellular phone applications | E 911 / E 112 | | | ✓ | | | | ✓ | | | | |
| | Car breakdown | | | ✓ | | | | ✓ | | | | |
| | Surveillance | | | ✓ | | | | ✓ | | | | |
| | Friend Finding | | ✓ | ✓ | | | | ✓ | | | | |
| Location-based services | A1-Mobilguide | | ✓ | ✓ | | | | ✓ | | | | |
| | 3 Geo | ✓ | ✓ | ✓ | | ✓ | | ✓ | | | | |
| | Lol@ | ✓ | ✓ | ✓ | | | | ✓ | | | | |
| | VISPA | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | |
| Systems for handicapped persons | MoBIC | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | |
| | Nottingham | ✓ | ✓ | | ✓ | ✓ | | | | | | |
| | Drishti | ✓ | ✓ | | | ✓ | | | ✓ | ✓ | ✓ | |
| | MERL | ✓ | ✓ | | | ✓ | ✓ | | | | | ✓ |

Table 1: Comparison of navigation systems and location-based services [4, 6, 9, 10, 13, 14, 15, 16, 17, 19, 20, 24]

| Method | Sensor | Observations | Accuracy |
| --- | --- | --- | --- |
| GNSS | e.g. Garmin GPS 35<br>DGPS | $y, x, z$ | 6-10 m<br>1-4 m |
| Indoor Positioning | e.g. WLAN Positioning IMST ipos | $y, x, z$ | 1-3 m |
| Cellular Phone Positioning | GSM<br>UMTS | $y, x$<br>$y, x$ | > 50 m<br>> 10 m |
| Dead Reckoning | e.g. PointResearch DRM-III Dead Reckoning Module | $y, x$<br>$z$<br>$\varphi$ | 20-50 m per 1 km<br>3 m<br>1° |
| Direction of Motion (Heading) | e.g. Honeywell Digital Compass Module HMR 3000 | $\varphi$ | 0.5° |
| Acceleration | e.g. Crossbow Accelerometer CXTD02 | $a_{tan}, a_{rad}, a_z$ | $> 0.03$ ms$^{-2}$ |
| Velocity from GNSS | e.g. Garmin GPS 35 | $v_y, v_x$<br>$v_z$ | ~ 0,05 m$^{-1}$<br>~ 0,2 m$^{-1}$ |
| Barometer | e.g. Vaisala Pressure sensor PTB220A | $z$ | 1-3 m |

Table 2: Sensors for pedestrian navigation systems with their observables and accuracies [1, 2, 7, 11, 12, 18, 25] where $y$, $x$, $z$ are the 3-D coordinates of the current position, $v_y$, $v_x$, $v_z$ are the 3-D velocities, $\varphi$ is the direction of motion (heading) in the ground plane $xy$, $a_{tan}$ is the tangential acceleration and $a_{rad}$ is the radial acceleration in the ground plane $xy$, $a_z$ is the acceleration in height ($z$ coordinate)

Employed sensors can be distinguished between absolute and relative positioning methods. Absolute sensors determine directly one or more components of the current 3-D position of the user. Typical examples are satellite positioning systems (GNSS), positioning systems for determination of the user's location in buildings, cellular phone location techniques and altimeter for height determination. For absolute position determination primarily GNSS is employed. In the case of no GNSS availability it can be replaced by location techniques using cellular phones [5, 9, 20] or indoor positioning systems (e.g. WLAN positioning [12, 22]). Apart from this sensors, relative DR (Dead Reckoning) sensors are employed for the observation of the travelled distance (from velocity and acceleration measurements), direction of motion or heading and height difference. Typical relative sensors are pedometer, compass and gyro, velocitymeter, acceleration sensors, inclinometer, low-cost Inertial Navigation Systems (INS) and barometer for measurement of height differences [e.g. 2, 11, 18, 25].

## 4 Integrated Positioning in the project NAVIO

The different navigation sensors should not be treated independently but a combined processing and estimation of the current user's position should be performed. Then the user gets in real-time an optimum estimate of the 3-D position and the velocity. In general, in most common navigation systems that are available on the market, however, not an integrated position determination, using observations of all available sensors, is performed. In vehicel navigation systems for instance the resulting trajectory is determined mainly based on the dead reckoning observations; GNSS is used for updating and resolving the systematic error growth of the DR observations and to obtain a start position. For guidance of a pedestrian in 3-D space and updating of his route, continuous position determination is required with positioning accuracies on the few meter level or even higher, especially for navigation in multi-storey buildings in vertical dimension (height) as the user must be located on the correct floor. The specialized research hypothesis of the work package "Integrated Positioning" of our research project NAVIO [8] is that a mathematical model for integrated positioning can be developed that provides the user with a continuous navigation support. Therefore appropriate location sensors have to be combined and integrated using a new multi-sensor fusion model. Further information about this new approach can be found in [22, 23].

## 5 Practical tests of our approach

Practical tests in our research project are carried out for the guidance of visitors of the Vienna University of Technology to certain offices in different buildings or to certain persons. Thereby we assume that the visitor employs a pedestrian navigation system with different sensors that perform an integrated positioning. Start points are nearby public transport stops, e.g. underground stop Karlsplatz in the center of Vienna or railway station Südbahnhof near our university.

To test the approach of integrated positioning, simulations have been performed [21, 22]. One test has been carried out for the guidance of a visitor from the underground stop Karlsplatz to an office building of the Vienna University of Technology and onward to the Secretary of our Institute in the 3rd floor of the building. The length of the path is approximately 500 m. Thereby the first part of the path (about 30 m) is in the underground passage of the subway stop, where an absolute start position is determined using cellular phone positioning and continuous positioning is performed using dead reckoning (see Figure 1). Outside the underground stop GPS positioning is available and therefore the position changes quite significantly as the absolute position determination is improved.

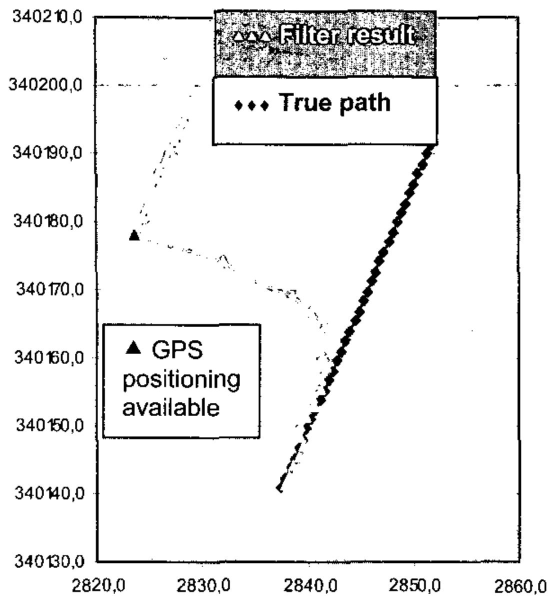


Figure1: Position determination at the start point in the underground stop Karlsplatz, Vienna and the first 30 m of the path in open area (Absolute start position is obtained using cellular phone positionining, position changes significantly after an absolute position is available from GPS measurements outside the underground stop)

The path of the user continues in a narrow street (i.e., Karlsgasse) where GPS outages can be bridged by the dead reckoning observations. The last part of the path (about 40 m) is in our office building. In this case, an indoor positioning system (e.g. WLAN positioning) is employed for determination of absolute location. Figure 2 shows the transition of position determination between the outdoor and indoor areas . It can be seen that a seamless transition can be achieved as the absolute positioning system changes. In addition, the height is observed using a barometer. All available observations are used to get an optimal estimate of the current location from the Kalman filter. Apart from the first part of the path in the underground stop where the absolute position from cellular phone positioning is not very precise, the standard deviation of the path of the pedestrian from the true value is in the range of a few metres although two GPS outages with a length of approximately 30 m and 90 m were simulated.

The simulation study presented showed promising results for the use of our approach for integrated position determination in different navigation applications, such as pedestrian navigation in dense high-rise urban environments, where GNSS signals are frequently blocked by surrounding building structures. Further practical tests will be carried out in the near future and their results will be presented elsewhere.

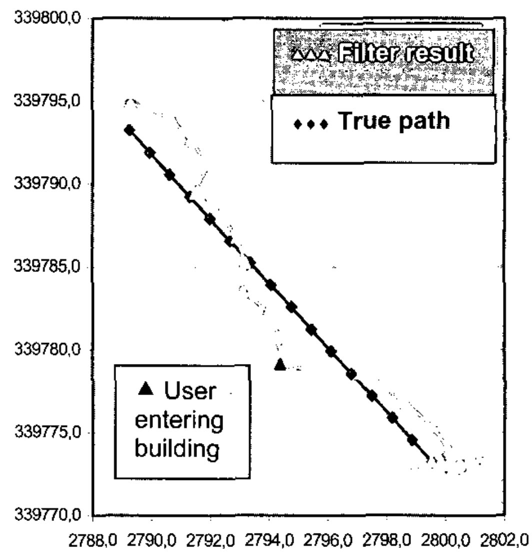


Figure 2: Position determination as the user enters the office building of the Vienna University of Technolgy, Gusshausstrasse 27-29, Vienna, Austria (No significant change in the absolute position determination between GPS outdoors and the indoor positioning system can be seen)

## 6 Conclusions

In the NAVIO project major aspects being important when concepting a pedestrian navigation service are investigated, i.e., integrated positioning, multi-criteria route planning, and multimedia route communication [see 8]. As a result, a specific pedestrian navigation service as use case will derive the requirements on positioning, route planning, and communication. A prototype of the service will guide visitors of the Vienna University of Technology to departments and persons. Practical tests will allow us to evaluate and demonstrate the usability of the service, and thus, prove the projects attempts.

With the work package "Integrated Positioning" of the project we will contribute to the integration of location sensors in the sense of a multi-sensor system to achieve a continuous positioning of the user of the service and a seamless transition between indoor and outdoor areas. Suitable sensors and location methods have been identified and the basic concept of a multi-sensor fusion model for integrated positioning has been developed [22, 23]. Special emphasis has been given on the location determination and navigation of a pedestrain in a multi-storey building. Currently we are investigating the use of WLAN positioning for location determination in indoor areas.

The second work package of the project NAVIO on "Pedestrian route modeling" is dealing with the ontological modelling of navigation tasks, deriving well founded criteria and optimization strategies in route selection; and the third work package on "Multimedia route communication" is working on models for context-dependent communication modes of route information.

In general, it can be said that the results of the project NAVIO will contribute to the improvement of modern (pedestrian) navigation services.

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