

Test and Integration of Location Sensors for Position Determination in a Pedestrian Navigation System

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Abstract

In the work package “Integrated Positioning” of the research project NAVIO (Pedestrian Navigation Systems in Combined Indoor/Outdoor Environments) we are dealing with the navigation and guidance of visitors of our University. Thereby start points are public transport stops in the surroundings of the Vienna University of Technology and the user of the system should be guided to certain office rooms or persons. For the position determination of the user different location sensors are employed, i.e., for outdoor positioning GPS and dead reckoning sensors such as a digital compass and gyro for heading determination and accelerometers for the determination of the travelled distance as well as a barometric pressure sensor for altitude determination and for indoor areas location determination using WiFi fingerprinting. All sensors and positioning methods are combined and integrated using a Kalman filter approach. Then an optimal estimate of the current location of the user is obtained using the filter. To perform an adequate weighting of the sensors in the stochastic filter model, the sensor characteristics and their performance was investigated in several tests. The tests were performed in different environments either with free satellite visibility or in urban canyons as well as inside of buildings. The tests have shown that it is possible to determine the user’s location continuously with the required precision and that the selected sensors provide a good performance and high reliability. Selected tests results and our approach will be presented in the paper.

Keywords: Integrated Positioning, Navigation in unfamiliar environment, Indoor location, Sensor fusion, Kalman filter.

1. Introduction

The acceptance of mobile personal navigation systems has grown in recent years. Many applications require nowadays the location determination and tracking of persons or objects in combined indoor and outdoor environments. Most personal navigation systems rely on location determination using GNSS in combination with map matching. In general, these systems show a high performance in case of availability and positioning accuracy. Very challenging, however, is the continuous position determination in urban areas where satellite signals are frequently blocked. In the NAVIO project (Gartner et al., 2004) the navigation of a pedestrian in combined indoor/outdoor environments is investigated and a system has been developed. Thereby one of the main challenges which have been investigated was the usage of dead reckoning sensors for the continuous position determination of a pedestrian. For this purpose different sensors have been tested and integrated into a system. The reliability of the location determination has to be improved in our system by the use of new multi-sensor fusion model based on a Kalman filter. As more sensors have been integrated than the minimal number required for continuous position determination, statements can be derived about the quality of each sensor for an optimal estimate of the current user’s position and its usability in the system design. In the following the sensors employed in NAVIO are described and their integration is discussed. Finally the test of the sensors is presented in the paper.

2. The NAVIO System Design

Figure 1 shows the employed sensors in the NAVIO system developed at the Vienna University of Technology. The

following sensors are integrated:

- Garmin eTrex Summit GPS receiver,
- Dead Reckoning Module DRM III from PointResearch,
- Honeywell digital compass HMR 3000, and
- Vaisala PTB 220 barometric pressure sensor.

In the system the selected GPS sensor is employed for absolute position determination and the other three sensors are used as dead reckoning sensors for relative position determination from a given start position. Using these sensors the travelled distance, the direction of motion and changes in altitude can be determined. For the data acquisition a software module has been developed using Matlab (Retscher and Thienelt, 2006). An optimal estimate of the current user’s position, its velocity and direction of motion is then obtained using a Kalman filter approach. For this purpose a new algorithm has been developed and was implemented using Matlab.

3. Sensor Integration using a New Multi-Sensor Fusion Model

For the integration of the different location sensors a multi-sensor fusion model based on an extended Kalman filter that makes use of a knowledge-based preprocessing of the available sensor observations has been developed. The concept of the new algorithm was presented in Retscher (2006) and Figure 2 shows the necessary steps of operation. In a first step the observations of each sensor of the multi-sensor system are analyzed in a knowledge-based preprocessing filter. In this step the plausibility of the observations is tested as well as gross errors and outliers are detected and eliminated. The analyzed and corrected observations are then used in the following central Kalman filter for the optimal estimation of the current user’s position and its velocity and direction of movement. In this processing step all

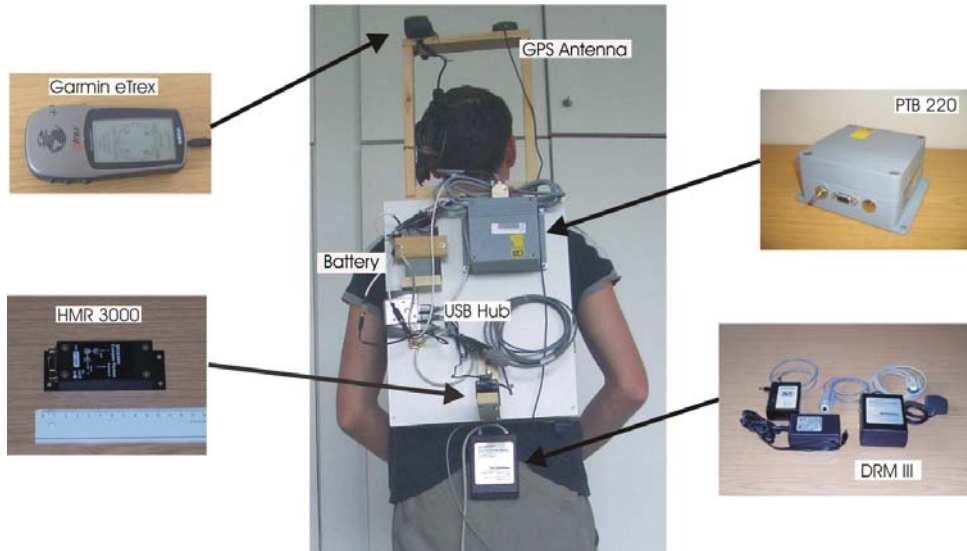


Figure 1. Sensors of the NAVIO system

suitable sensor observations as identified before are employed and the stochastic filter model is adapted using the knowledge of the preprocessing step. For example, the weightings of the GPS observations can be reduced in the case if the current GPS positioning accuracy is low due to a high GDOP value (i.e., bad satellite-receiver geometry) or other error sources (e.g. multipath). Then the optimal estimate of the user's position should be more based on the observations of other sensors (e.g. dead reckoning observations). This approach will lead to an optimal estimate of the current user's position, its direction of motion and velocity.

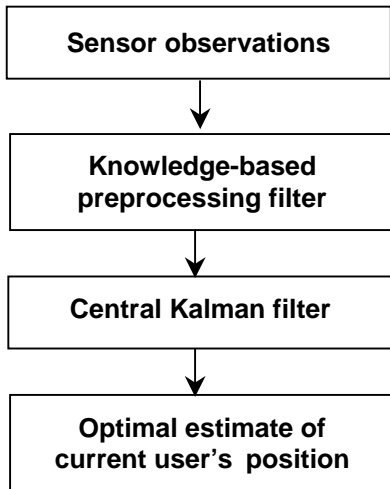


Figure 2. Process flow of the intelligent multi-sensor fusion model (after Retscher, 2006)

In the Kalman filter two different kinematic filter models were tested which describe a linear radial movement behaviour of the pedestrian. Then the accelerations are taken into account in the stochastic disturbance vector of the Kalman filter. In the first model a kinematic formulation of the movement of the pedestrian is performed (see Wang, 1997) whereas in the second model also sudden changes in the direction of motion of the pedestrian are taken into account (see Retscher and Thienelt, 2006; Eichhorn, 2005). In the first kinematic filter model the following system equations are used:

$$Y(k+1) = Y(k) + v_t(k) \sin(\alpha(k)) (t_{k+1} - t_k) + \frac{1}{2} a_r(k) \cos(\alpha(k)) (t_{k+1} - t_k)^2 \quad (1)$$

$$X(k+1) = X(k) + v_t(k) \cos(\alpha(k)) (t_{k+1} - t_k) - \frac{1}{2} a_r(k) \cos(\alpha(k)) (t_{k+1} - t_k)^2 \quad (2)$$

$$\alpha(k+1) = \alpha(k) + \frac{a_r(k)}{v_t(k)} (t_{k+1} - t_k) \quad (3)$$

$$v_t(k+1) = v_t(k) \quad (4)$$

$$a_r(k+1) = a_r(k) \quad (5)$$

where $X(k)$ and $Y(k)$ are the 2-D coordinates, $\alpha(k)$ is the azimuth, $v_t(k)$ is the tangential velocity and $a_r(k)$ is the radial acceleration.

Disturbances to the system are caused by a scalar tangential acceleration $a_t(k)$ and in radial direction by the derivative of the radial acceleration $\dot{a}_r(k)$ (i.e., the so-called radial jerk). Due to the selected time interval the impact of the disturbances is reduced to a minimum. Therefore we can assume for the expectation value $E\{a_t\} = 0$ und $E\{\dot{a}_r\} = 0$. Over one epoch of the filter the two disturbance values can also be considered as constant.

4. Location Sensor Testing

The performance and the accuracy of these sensors was tested in different test areas. For the test areas different environments representing the real world situation for the system were chosen. One test area was in the park of Schönbrunn palace with free satellite visibility, the second in urban environment in the surroundings of our University building and the third indoor in our office building. The sensor tests also provided very important information for the deduction of the stochastic Kalman filter model for the integration of the sensor observations.

4.1 GPS Sensor Tests

Two different GPS sensors are available, i.e., the Garmin eTrex and the in-built GPS sensor of the dead reckoning module DRM III of the company PointResearch. The availability and reliability of this sensors in urban areas has been tested. The observations have been compared with a surveyed reference trajectory. For the Garmin eTrex a RMSE for the absolute

coordinates of ± 3 m and relative positioning accuracies on the dm-level could be obtained. For the DRM III, however, the absolute positioning accuracy is the range of ± 5 to 8 m and relative positioning accuracies on the m-level. Also the availability and reliability of the Garmin eTrex in urban canyons is higher than the DRM III receiver.

4.2 Heading Sensor Tests

To analyze the performance of the heading sensors long term lab observations for determination of the sensor drift and test observations in the real world situation have been performed. From the long term observations the manufacturers specs can be checked and a significant drift can be detected. In the tests of the Honeywell HMR 3000 heading sensor no significant drift rate could be seen and an average standard deviation of ± 0.22 degrees with maximum deviations of 1.2 degrees was obtained. For the heading sensor of the PointResearch DRM III a standard deviation of ± 0.85 degrees with maximum deviations of 3.6 degrees was obtained. In addition, the influence of magnetic disturbances on the heading observations was tested. The results were presented in Retscher and Thienelt (2005). As an example Figure 3 shows the influence of lanterns along the way of the pedestrian. Large deviations occurred if the source of disturbance is very close to the sensor. Also the influence of other system components, i.e., the notebook computer, barometric pressure sensor Vaisala PTB 220, or a metallic lighter have been tested. Here deviations of 2 to 3 degrees occurred if the source of disturbance is put in a distance of about 30 cm from the sensor. Higher deviations occur, however, at shorter distances to the sensor. As a consequence the sensor should be kept away from any sources that can cause disturbances such as mobile phones, coins, metallic lighters and keys.

If the sensors are employed for the heading determination of a pedestrian in the real world situation, however, larger standard deviations than in the lab tests could be seen. The main reason for this is that the movement of a pedestrian depends very much on the walking surface (e.g. paved road, uneven surfaces, etc.) and the walking behavior (i.e., walking, running, etc.). On asphalt surfaces standard deviations of ± 2 to 3.5 degrees were obtained for the DRM III sensor and ± 3.5 to 4.5 degrees for the HRM 3000. As the limiting factor is the movement behavior of the pedestrian and the walking surface, we can conclude that the use of such low cost sensors for the heading determination fulfills our system requirements.

4.3 Barometric Pressure Sensor

The direct altitude determination is especially necessary in indoor environments. Using a barometric pressure sensor we want to be able to locate the user on the correct floor of a multi-storey building. Two different sensors have been analyzed, i.e., the internal barometer of the PointResearch DRM III module and the Vaisala pressure sensor PTB 220. First of all the accuracy and the drift rate of both sensors were investigated in long term lab tests. In this tests we could see that the standard deviation for the altitude determination of the PTB 220 is in the range of ± 0.11 to 0.33 m and for the DRM III in the range of ± 1 m. Maximum deviations of ± 0.60 m were obtained for the PTB 220 and ± 3 m for the DRM III.

Further tests were conducted in our office building of the Vienna University of Technology for location determination of a user on the correct floor. Figure 4 shows the observations with the PTB 220 and DRM III inside the building. As can be seen from Figure 4, the PTB 220 can determine the floor of the user very precisely (Figure 4 on the left), whereas the deviations of the barometer in the DRM III are much larger (Figure 4 on the right). Using the DRM III it could happen that the user is located on the wrong floor of the building as the standard deviations are larger than the height difference of the floors (i.e., 3.7 m). To conclude we can therefore recommend that a more precise and expensive barometric pressure sensor such as the Vaisala PTB 220 should be integrated into a pedestrian navigation system if the user has to be located also in indoor environments.

4.4 Measurement of the Travelled Distance

The measurement of the travelled distance is performed using the acceleration sensors of the PointResearch DRM III. The DRM III module is clipped on the users belt on the back and the observations of the acceleration sensors are used to detect the steps and count their number. In several tests the quality of the stride detection was tested in dependence of the walking behaviour of the pedestrian. For that purpose the number of steps was counted manually from the user and the result was compared with the DRM III measurements. Over a distance of about 70 m differences in the number of steps of 1 to 2 steps occurred which would result in an error in distance of about 1.5 m. The error, however, is larger if the pedestrian changes quickly the walking speed between walking and running as only an average value for the stride length is taken into account.

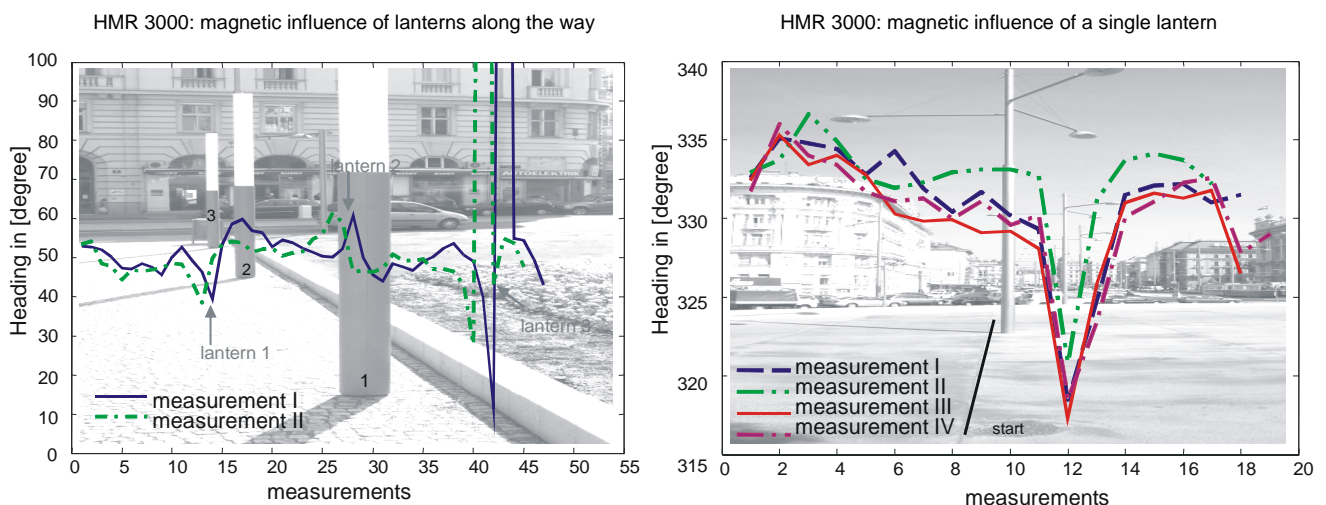


Figure 3. Magnetic influences of lanterns along the way on the observations of the Honeywell HMR 3000

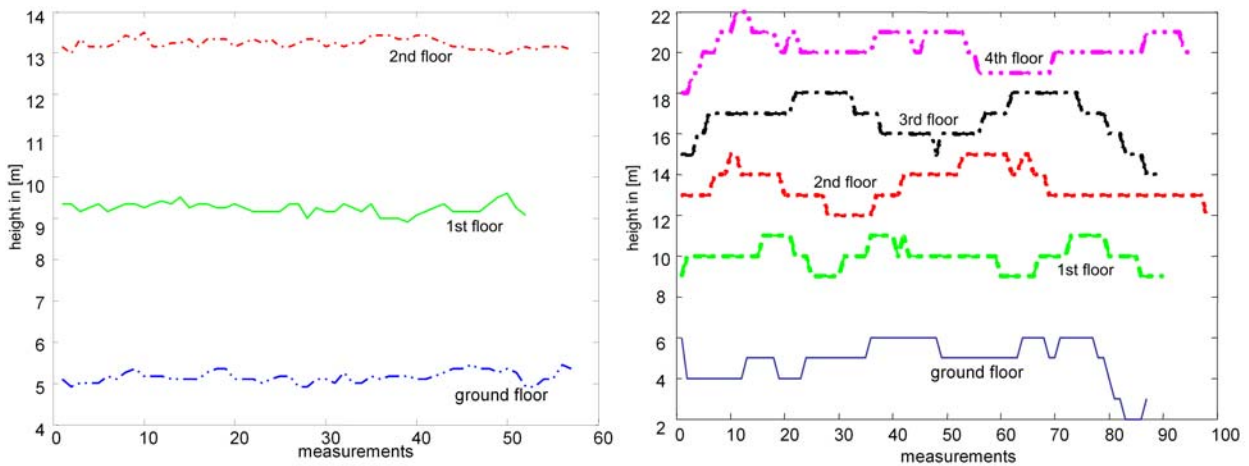


Figure 4. Indoor observations with the PTB 220 (left) and the barometer of the DRM III (right) for the determination of the correct floor of the user in a multi-storey building

4.5 General Remarks

Apart from the determined standard deviations of each employed sensor described in section 4.1 to 4.4., a main result of the sensor tests was that it is very challenging to determine the correct travelled distance and the direction of motion of the user. For the determination of the direction of motion of the user not only the quality of the heading observations using the digital compass is the limiting factor but also the movement behaviour of the walking pedestrian is very critical.

5. Sensor Integration Performance Test

A main goal of the development of the new sensor fusion model is the improvement of the reliability of location determination in urban environments. To test our approach the system was tested in the surroundings of our University. Figure 5 shows the test area in the 4th district of Vienna where typically 5 to 6-storey buildings are located along narrow streets. In the north of the selected area the trajectory starts in the Resselpark, then it continues along Argentinierstrasse and Gusshausstrasse to Karlsgasse and returns to the start point. At the intersection of Gusshausstrasse and Karlsgasse our office building is located. Figure 5 on the left shows the positioning result of the PointResearch DRM III module and Figure 5 on the right the result of all suitable sensor observations of the NAVIO system. The red line in Figure 5 (left) shows the GPS positions of the DRM III module. Due to bad satellite reception along the Karlsgasse and the large positioning errors of the GPS receiver, the DRM III system is not able to perform a continuous position determination from the start point in the Resselpark (in the north) to the same end point as in the Karlsgasse the drift of the dead reckoning sensors is to large and no useable update from GPS is available anymore. On the other hand, Figure 5 on the right shows the result of our calculated trajectory using the new multi-sensor fusion approach. As can be seen from Figure 5 (right), a continuous position determination is possible using all suitable sensor observations. Also the positioning accuracy of the determined trajectory is much higher. Larger errors in the range of 7.5 m from the reference trajectory occurred only along Gusshausstrasse and at the intersection of the Gusshausstrasse and Karlsgasse. A further improvement at sharp turns is expected using the improved filter approach which takes also sudden changes in the direction of motion of the pedestrian into account (compare section 3).

6. Indoor Location Determination

Further research in the NAVIO project was carried out for the investigation of indoor location techniques. As most systems provide only location capability in two dimensions, the augmentation of an indoor location system with a barometric pressure sensor for direct observation of the altitude of the user was investigated. As shown in section 4.3, we were able to determine the correct floor of a user in a multi-storey building using the Vaisala PTB 220 pressure sensor. Testing has been performed in our office building of the Vienna University of Technology. For the absolute position determination inside the building the use of Wireless LAN or WiFi was investigated (Retscher et al., 2006). This approach has the advantage that already available infrastructure in our office building can be employed. For this purpose a cooperation with the German company IMST GmbH was established and they provided the indoor location system 'ipos'. The system 'ipos' uses standard WiFi hardware and the location determination of a mobile user can be performed on the mobile terminal or a server in the network. First of all a calibration of the system in an offline phase is required. During the calibration signal strength measurements are performed at known location in the test area and stored in a database. Then in the online phase a mobile user can be located. The accuracy and performance of the system was tested in a diploma thesis in the localization testbed of IMST GmbH in Germany. The system is now available in our office building of the Vienna University of Technology and can be employed in combination with the dead reckoning sensors. It has been tested recently and the results are presented in Retscher and Mok (2006). In the tests it could be seen that the trajectory of the moving user could be obtained with a standard deviation of about ± 3 m.

7. Conclusions And Outlook

Different location techniques and sensors for pedestrian navigation and guidance have been tested in the NAVIO project at the Vienna University of Technology, Austria. For the integration of all available sensor observations a new multi-sensor fusion model has been developed. Using the new multi-sensor fusion approach a high reliability and location accuracy for continuous position determination of a pedestrian in urban environments can be achieved. The approach makes use of a knowledge-based component for a preprocessing of all available sensor observations (Retscher, 2006). In this

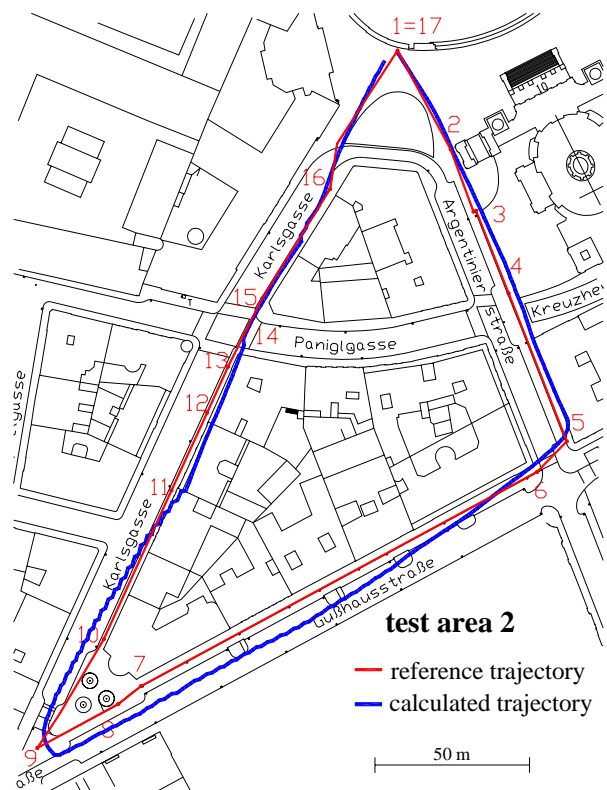
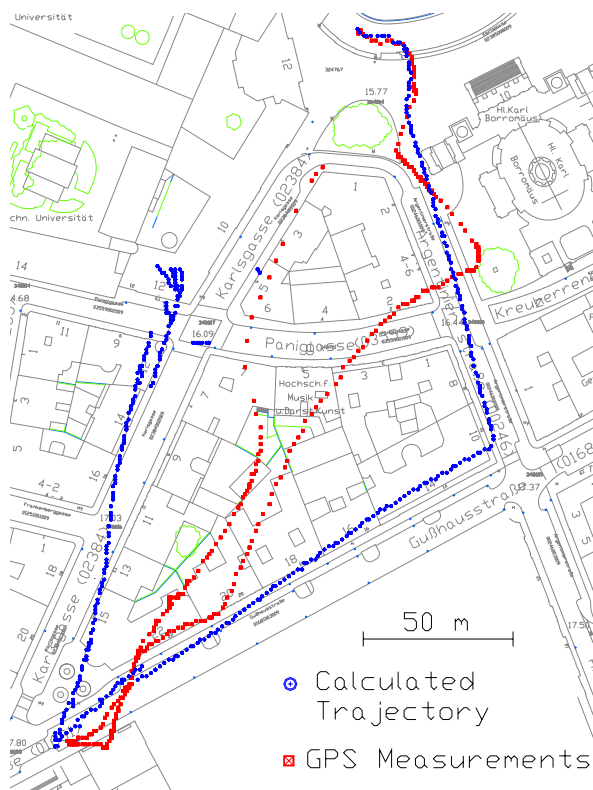


Figure 5. Urban test area in the 4th district of Vienna with DRM III trajectory (left) and NAVIO multi-sensor system trajectory (right)

preprocessing step outliers and large errors are detected and these observations are then not used in the central Kalman filter. In addition, the knowledge of the preprocessing filter is used to adapt the stochastic Kalman filter model. Test result have shown that the positioning performance and reliability of continuous location determination can be significantly improved using this approach. Using the NAVIO system a user can be located in combined indoor and outdoor urban environments with high precision. Maximum deviations in the range of a few metre were achieved in urban environment. Apart from GNSS, dead reckoning sensors such as a digital compass for heading determination, accelerometers for the measurement of the travelled distance and a barometric pressure sensor for altitude determination are employed. For indoor environments currently WiFi fingerprinting has been used. In the future also the use of RFID (Radio Frequency Identification) for positioning using active landmarks is planned. A concept for the placement of the RFID tags (or transponders) at active landmarks in indoor environment has been developed and was presented in Retscher and Zhang (2006). This strategy will be further investigated in the near future.

Acknowledgement

Part of the research work presented in this paper is supported by the FWF Project NAVIO of the Austrian Science Foundation (Fonds zur Förderung wissenschaftlicher Forschung) (Project No. P16277-N04).

The WiFi positioning system 'ipos' was kindly provided by the German company IMST GmbH (<http://www.imst.de/>) and they also provided financial support for the performed tests in their localization testbed.

The author would also like to thank Mrs. Eva Moser and Mr. Christoph Hiller for their assistance in the performance of some of the test measurements with the location sensors.

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