Location Determination in Indoor Environments for Pedestrian Navigation

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***Abstract*-For the location determination of persons and objects in indoor environments a variety of systems have been developed in recent years. The main methods are described and compared in this paper, i.e., location methods using infrared, ultrasonic or radio signals and optical tracking systems. Thereby it can be distinguished if the system is specially designed for positioning and has to be installed in the building or if already available infrastructure (such as WiFi, UWB or Bluetooth) is employed. The indoor location techniques can be integrated in modern navigation systems where also a location determination of the user in a building is required apart from positioning in urban outdoor environments. As most common indoor location techniques provide only 2-D position determination, however, a challenging task is to determine the correct floor of a user in a multi-storey building. In this case it can be recommended to augment the positioning system with a barometric pressure sensor for direct observation of height differences. In the research project NAVIO (Pedestrian Navigation Systems in Combined Indoor/Outdoor Environements) conducted at our University tests with different sensors have been performed. The tests have shown 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. Currently a combination of WiFi positioning with a barometric pressure sensor and other dead reckoning sensors (for observation of the direction of motion and traveled distance) is tested in our office building. A typical application would be the guidance and navigation of a pedestrian who is unfamiliar with the environment to a a certain office or a person at the Vienna University of Technology. The selcted approach and test results will be presented in the paper.**

***Keywords*-Pedestrian navigation systems, Indoor location techniques, WiFi positioning, Altitude determination using a barometric pressure sensor, Navigation and guidance.**

I. Introduction

Many applications require nowadays not only the location determination and tracking of persons or objects in outdoor environements but also inside buildings and in combined indoor/outdoor urban environments. Indoor location estimation is particularly challenging as GNSS signals are usually too weak to penetrate into buildings. Tracking people and objects using alternative techniques is therefore required. Wireless positioning techniques have attracted much interest and research recently, since they represent a core enabling technology for a continuously increasing number of mobile locating applications. In this paper an overview of indoor location techniques is given followed by a more detailed analysis of the use of Wireless Local Area Network (or WiFi) signals for indoor location determination. Recent performance test results of the WiFi positioning system 'ipos' in a localization testbed are presented. For 3-D location determination the system will be augmented with a barometric pressure sensor for direct observation of the altitude in the building. Using this sensor we are able to determine the correct floor of a user in a multi-storey building. Test results using the Vaisala pressure sensor PTB 220 are presented.

In addition, other dead reckoning sensors for the measurement of the traveled distance and the direction of motion (or heading) are also necessary in a pedestrian navigation system and have been integrated in the design of the NAVIO system. The employed sensors are presented and their integration using a multi-sensor fusion model is briefly described.

II. Indoor Location Techniques

Different location techniques have been developed for indoor positioning. They use signals such as infra red, ultra sonic, radio signals or visible light. 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 strenght measurement for location determination using fingerprinting (e.g. WiFi fingerprinting, see section III) where the signal strenght 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 [19]. Table I gives an overview about different indoor location techniques.

The systems Active Badge [25] and WIPS [22] employ infra red signals for location determination, Active Bat [8] and Cricket [22] use ultra sonic signals. For the location of cellular phones (e.g. in the GSM network) ToA or TDoA measurements can be performed [14]. Satellite or similar signals are also employed for the location determination of cellular phones using Assisted GPS (A-GPS) or for the

TABLE I
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 I:

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

Postioning Methods:
CoO..... Cell of Origin
ToA..... Time of Arrival
TDoA... Time Difference of Arrival
AoA..... Angle of Arrival
SS....... Signal strenght measurement
DI....... Digital images

N/A......Information not available

Australian system Locata [2] which makes use of standard RTK positioning with GPS similar signals. For indoor positioning the use of WiFi (Wireless Local Area Networks) has become popular and the systems Radar [1], IMST ipos [10], Ekahau [4] and WhereNet [26] are using WiFi. Apart from WiFi also Ultra Wide Band (UWB) signals and Bluetooth [6] can be employed. SpotON [7] employs also radio signals and perfoms signal strenght measurements.

RFID (Radio Frequency Identification) can also be employed for indoor positioning if the RFID tags are placed at known locations inside the buildings and the user is carrying a RFID reader. If the user pases by with the 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. Using active RFID tags therefore the positioning accuracy ranges between a few metres up to tens of metres and with passive tags up to about 5 m. Altough this positioning accuracy can be low for some applications, RFID positioning can be very useful in combination with other sensors (e.g. dead reckoning sensors, see section V).

Table I also contains three systems using digital images for location determination, i.e., CyberCode [13], Ubitrack [11] and EasyLiving [3]. For a further description of these systems see e.g. [21].

III. Principle and Performance of WiFi Fingerprinting

The use of already available wireless infrastructure for location determination can reduce system costs significantly. WiFi (or WLAN) is nowadays widely adopted; in particular the comfortable and mobile access to the internet were here the driving factors. Access points can be found in our daily environment, e.g. in many office buildings, public spaces and in urban areas. A common approach for the localization of a handheld terminal or mobile device by means of WiFi is based on measurements of received signal strengths of the WiFi signals from the surrounding access points at the terminal. This information is available due to the beacon broadcast multiple times a second by every access points. An estimate of the location of the terminal is then obtained on the basis of these measurements and a signal propagation model inside the building. The propagation model can be obtained using simulations or with prior calibration measurements at certain locations. In the second case, the measured signal strengths values at a certain location in the building are compared with the signal strengths values of calibrated points stored in a database. This technique is also referred to as fingerprinting.

The German based company IMST GmbH has developed a software platform as a basis for the realization of LBS applications [10]. It consists of an efficient, freely parameterizable framework, which is suitable for multiple application architectures. Thereby signal strength measurements are performed on user terminals, while evaluations and visualizations can take place if necessary on user terminals. The developed positioning system “ipos” makes use of a standard WiFi infrastructure and no modification of the hardware is required.

Fig. 1 shows the “ipos” system design and the software framework. The software framework supports multiple localization techniques. For example, in the WiFi (or WLAN) case, the user terminal measures signal strengths, while calculations and visualizations can be performed within the network or at the user terminal. Once the post-processing step is reached, all data is independent of its underlying wireless technology. Using different processing steps, the estimation can be adapted to the application’s needs. Data fusion allows then for a seamless handover between multiple localization techniques. Further information about the system can be found in [20].

In a study the performance and the achievable positioning accuracies of the positioning system “ipos” have been tested. This study was conducted in cooperation between the Vienna University of Technology and IMST GmbH. The tests were performed in a localization testbed in an office building of IMST in Germany [20]. In the following some tests results for the location determination of a user in an office room are presented. In the office rooms usually one or two calibration points are located. The calibration measurements are required at the beginning to store the signal strengths values of points with known location in the database of the system. For the tests also a continuously moving user and a standing user were investigated. Exemplary Fig. 2 shows the position fixes of a moving user in a room where on the left the position fixes using one calibration point and on the right the position fixes using two calibration points are shown. In both cases the majority of the observed points lies inside the room (86% in the case of 2 calibration points and 69% in the case of 1 calibration point). In addition, a tolerance zone was drawn around the room of double the room size. In this tolerance zone 98% of the position fixes are located if two calibration points are used and 82% if one calibration point is used.

From the several tests it can be summarized that the probability that a position fix is located inside the room is higher if two calibration points are used. If only one calibration point was used then only in half of the tested rooms more than 50% of all position fixes are inside. If the tolerance zone is considered the performance of the observations using only one calibration point is improved. The performance improvement is in average 22%. On the other hand, the performance improvement is in average 13% if two calibration points were used. It can therefore be recommended that two calibration points should be located in every room to have the majority of position fixes located

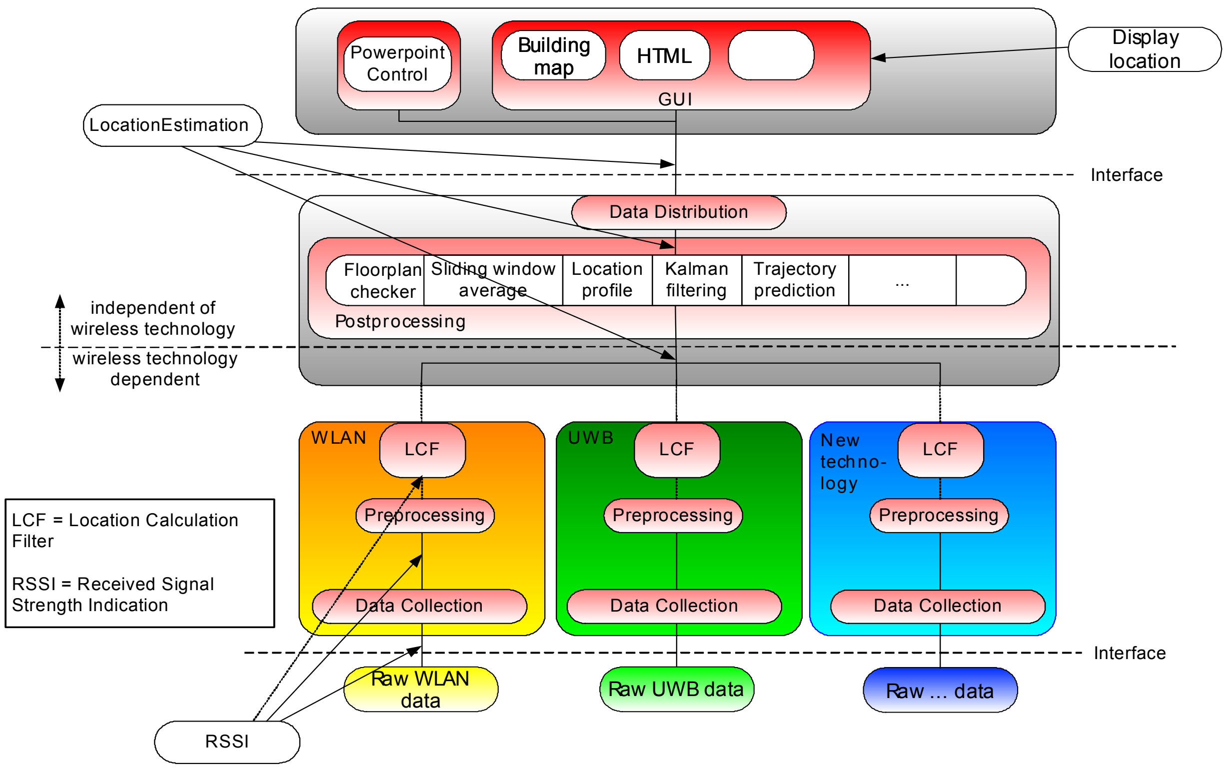

Fig. 1. The 'ipos' system design [10]

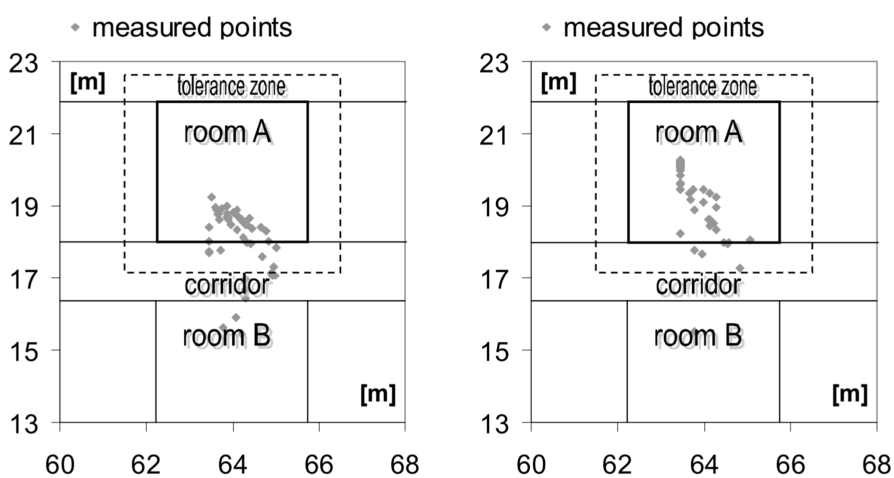

Fig. 2. Position fixes of a moving user in an office room using one (left) or two (right) calibration points inside the room

inside the room. The tests have also shown that there is no significant difference between the observations in the standard office rooms and the foyer of the building.

Fig. 3 shows the trajectory of the user from one side of the teste area to the other along the corridor and the foyer. The width of the corridor is approximately 1.8 m. In this case a sliding window average of the position fixes taking into account the previous three position fixes has been performed. As can be seen from Fig. 3 the system is able to position the user with a high accuracy along the corridor. Using the system we are able to locate a person or object in an office room or the corridor with a standard deviation of ± 1-3 m [20].

IV. Altitude Determination Inside a Multi-Storey Building

The main disadvantage of most indoor location techniques described above is that they usually provide only location capability in two dimensions. Therefore it can be recommended to augment the 2-D positioning with an additional sensor which is capable to determine the altitude of the user, i.e., to determine the correct floor of the user in a multi-storey building. In our research project NAVIO the altitude of the user is determined using a barometric pressure sensor. The performance and the achievable accuracy of the height determination using the Vaisala

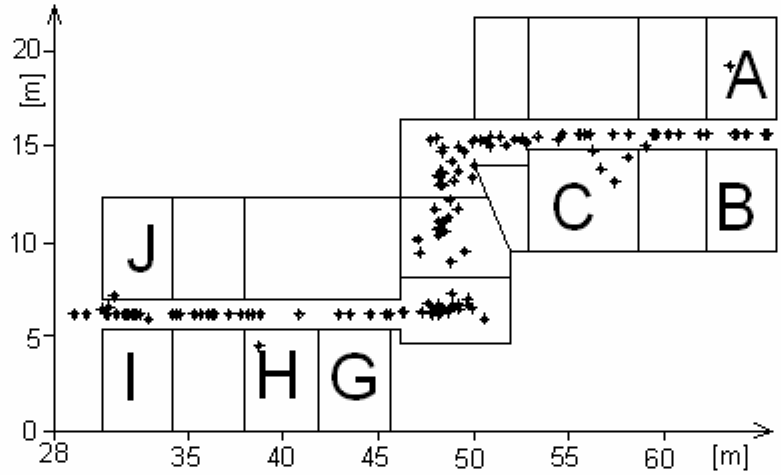

Fig. 3. Position fixes of a moving user along the corridor from rooms I and J to A and B

barometric pressure sensor PTB 220 was tested and the results are briefly sumarized in the following.

The Vaisala pressure sensor PTB 220 can be employed for the determination of height differences from changes of the air pressure. The PTB 220 is designed for measurements in a wide environmental pressure and temperature range with an extremly high accuracy [24]. Starting from a given height the pressure changes can be converted in changes in height using the following equation:

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

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.

Tests performed in our 5-storey office building have shown that we are able to determine the correct floor of a user in a multi-storey building using this sensor. Fig. 4 shows the result of the altitude determination of the user entering the building at the main entrance and walking up the staircase to the third floor where our offices are located. As can be seen from Fig. 4 the sensor is able to determine the current floor with a high precision. The maximum deviations from the known height are less than ± 1 m for more than 90 % of all observations and the standard deviation of the pressure observation is in the range of ± 0.2 hPa. The deviations depend, however, on the time of day; higher deviations occured during noon where usually more people are inside the building and higher variations of the air pressure can be seen caused by higher air circulation due to frequent opening of doors and windows. The maximum outlier during noon reached values of about 1.4 m. In summary, it can be concluded that the sensor is

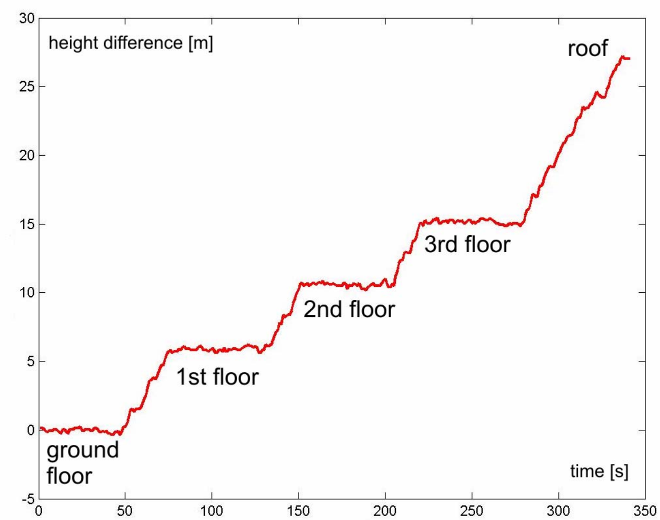

Fig. 4. Altitude observations with the Vaisala pressure sensor PTB 220 in our office building of the Vienna University of Technology

able to locate the user on the correct floor in the multi-storey building.

V. Other Location Sensors Employed in NAVIO

The integration of different location technologies and sensors is essential for the performance of modern advanced pedestrian navigation systems. Common navigation systems, however, rely mainly on satellite positioning (GNSS) for absolute position determination. Losses of lock of satellite signals are usually bridged using dead reckoning (DR) observations. Due to the main limitations of the sensors (i.e., satellite availability in the case of GNSS in urban areas and large drift rates in the case of DR) other positioning technologies such as WiFi fingerprinting were integrated into the system design of the NAVIO system to augment GNSS and DR positioning.

The following dead reckoning (DR) sensors are employed in the NAVIO system (see Fig. 4):

- dead reckoning module DRM III from PointResearch,
- Honeywell digital compass module HMR 3000, and
- Vaisala pressure sensor PTB 220 (see section IV).

The dead reckoning module DRM III from PointResearch [12] is a self contained navigation unit. It provides independent position information based on the user's stride and pace count, magnetic north and barometric altitude. The module is designed to self-calibrate when used in conjunction with an appropriate GPS receiver, and can produce reliable position data during GPS outages. The system consists of an integrated 12 channel GPS receiver, antenna, digital compass, pedometer and altimeter. The module is clipped onto the user's belt in the middle of the back and the GPS antenna may be attached to a hat. Firmware converts the sensor signals to appropriate discrete parameters, calculates compass azimuth, detects footsteps, calculates altitude and performs dead reckoning position calculation. An internal Kalman filter algorithm is used to combine dead reckoning position with GPS position to obtain an optimum estimate for the current user's position and track. With the dead reckoning module and GPS integrated together, a clear view of the sky is only required for obtaining the initial position fix. The fix must produce an estimated position error of 100 m or less to begin initialization. Subsequent fixes use both dead reckoning and GPS data, so obstructed satellites are not as critical as in a GPS only configuration. The Kalman filter continuously updates calibration factors for stride length and compass mounting offset. The GPS position error must be less than 30 m before GPS data will be used by the Kalman filter, and the first such fix will also initialize the module's latitude and longitude. Subsequently, the filter will use any GPS position fix with an estimated position error of 100 m or less, adjusting stride, body offset, northing, easting, latitude and longitude continually.

The Honeywell digital compass module HMR 3000 is employed in the project NAVIO for precise heading determination of the pedestrian. The HMR 3000 consists of a magnetic sensor and a two-axis tilt sensor [9]. The low power, small device is housed in a non-magnetic metallic enclosure that can be easily installed on any platform. A sophisticated auto compass calibration routine will correct for the magnetic effects of the platform. Wide dynamic range of the magnetometer allows the HMR 3000 to be useful in applications with large local magnetic fields. The influence of magnetic disturbances on the sensor has been tested and is presented in [18]. It could be seen that deviations of only 2 to 3 degrees occurred if the source of disturbance (e.g. a notebook computer or a metallic lighter) 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.

Fig. 5 shows the location sensors and their integration in a prototype system.

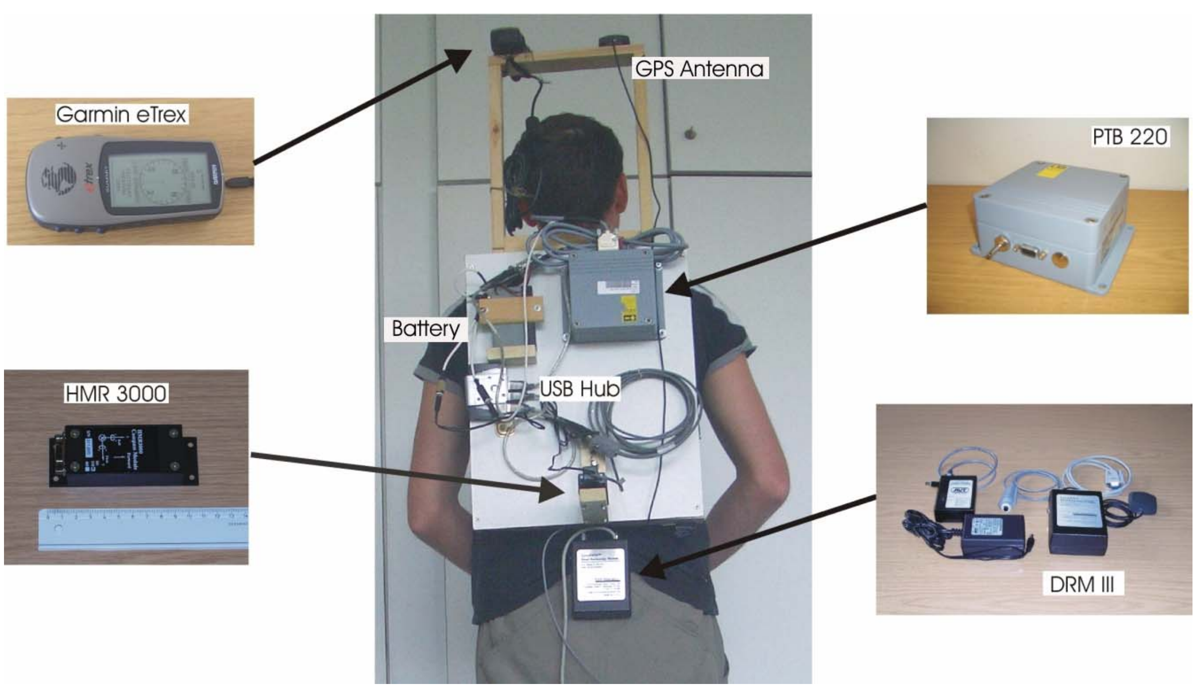

Fig. 5. Sensors of the NAVIO system

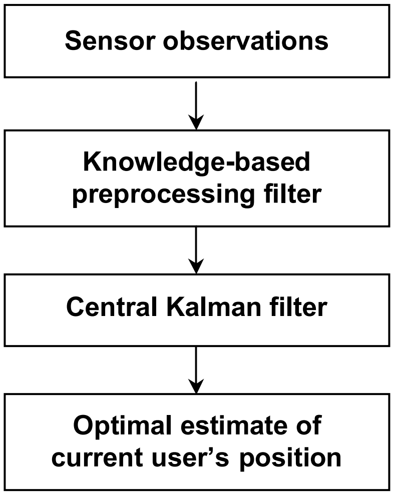

Fig. 6. Process flow of the intelligent multi-sensor fusion model [16]

VI. Sensor Integration

For the integration of the different location sensors a multi-sensor fusion model based on an extend Kalman filter that makes use of a knowledged-based preprocessing of the available sensor observations is currently under development. The concept of the new algorithm was presented in [16] and Fig. 6 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 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 [16].

VII. Concluding Remarks and Outlook

To provide a reliable and continuous position determination a pedestrian navigation system should include the following location technologies and sensors:

- GNSS for outdoor positioning,
- an indoor location system such as WiFi fingerprinting or RFID,
- dead reckoning sensors for the measurement of the traveled distance and the direction of motion or heading, and
- a pressure sensor for altitude determination.

These sensors and location techniques have been integrated into the NAVIO system which has been developed at the Vienna University of Technology. Testing of the system has shown that we are able to locate the user with a high reliability and accuracy. The system will be employed for the guidance of visitors of our University to certain offices from public transport stops in the future.

The WiFi location system has recently been installed in our office building and we are currently working on its integration in our multi-sensor system. Using the WiFi system it is possible to locate the user with a positioning accuracy in the range of 1 to 3 m. So it is possible to locate the user in an office room.

For the integration of all sensor observations a multi-sensor fusion model which makes use of a knowledge-based preprocessing of the sensor observations is employed. Using this approach an optimal estimate of the current user's position, its velocity and direction of motion can be obtained. For the estimation only suitable sensor observations are employed which have passed a plausibility check and where gross errors and outliers have been eliminated. In addition, the weightings of the individual sensors in the stochastic model of the Kalman filter is adapted using the knowledge of the preprocessing step. 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 combined outdoor and indoor environments will be deployed in pedestrians navigation services in the near future. We believe that these services will play an important role in the field of location-based services.

Apart from the continuous location determination of the user also the calculation of the best route providing the least risk path from the start point to the destination is performed in a second work package in the project as well as the presentation of the route and the current location using multimedia cartographic presentation forms in a third workpackage. Further information regarding these two work packages can be found in e.g. [5].

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REFERENCES

[1] P. Bahl and V. Padmanabhan, "Radar: An In-Building RF-based User Location and Tracking System", Proceedings of IEEE Infocom, Tel-Aviv, March, 2000, pp. 775-784.

[2] J. Barnes, C. Rizos and J. Wang, "Locata: A New Positioning Technology for High Precision Indoor and Outdoor Positioning", in: Papers presented at the ION GPS/GNSS 2003 Conference, September 9-12, 2004, Portland, Oregon, USA, (Institute of Navigation, Fairfax, Virginia), unpaginated CD-ROM.

[3] B. Brumitt, B. Meyers, J. Krumm, A. Kern and S. Shafer, "EasyLiving: Technologies for Intelligent Environments", Microsoft Corporation, 2000.

[4] Ekahau, "Ekahau Homepage", http://www.ekahau.com, (last date accessed: March 2006).

[5] G. Gartner, A. Frank and G. Retscher, "Pedestrian Navigation System in Mixed Indoor/Outdoor Environment – The NAVIO Project", in: Schrenk M. (ed.): CORP 2004 and Geomultimedia04. Proceedings of the CORP 2004 and Geomultimedia04 Symposium, February 24-27, 2004, Vienna, Austria, pp. 165-171, http://corp.mmp.kosnet.com/CORP_CD_2004/archiv/papers/CORP2004_GARTNER_FRANK_RETSCHER.PDF, (last date accessed: March 2006).

[6] J. Hallberg, M. Nilsson and K. Synnes, "Bluetooth Positioning", Proceddings of the 10th International Conference on Telecommunications (ICT), Tahiti, Feb. 23 – March 1, 2003.

[7] J. Hightower, R. Want and G. Boriello, "SpotON: An Indoor 3D Location Sensing Technology Based on RF Signal Strength", University of Washington, Department of Computer Science and Engineering, 2000.

[8] J. Hightower and G. Boriello, "A Survey and Taxonomy of Location Systems for Ubiquitous Computing", Technical Report, University of Washington, Department of Computer Science and Engineering, 2001.

[9] Honeywell, "HMR 3000 Digital Compass Module", User's Guide, Honeywell International Inc., USA, 2005, http://www.ssec.honeywell.com/magnetic/datasheets/hmr3000_manual.pdf (last date accessed: March 2006).

[10] IMST GmbH, "Indoor Positioning – Imst ipos," Project c21, IMST GmbH, Kamp-Lintfort, Germany, http://www.centrum21.de/ (last date accessed: March 2006).

[11] J. Newman, M. Wagner, M. Bauer, A. Mac Williams, T. Pintaric, D. Beyer, D. Pustka, F. Strasser, D. Schmalstieg and G. Klinker, "Ubiquitous Tracking for Augmented Reality", Technical Report, Vienna University of Technology, 2004, http://www.ims.tuwien.ac.at/media/documents/publications/ubitrackismar04.pdf, (last date accessed: March 2006).

[12] PointResearch, "Gyro DRM™ Gyro-Stabilized Dead Reckoning Module", PointResearch Corporataion, USA, http://www.pointresearch.com/datasheets/gyrodrm.pdf (last date accessed: March 2006).

[13] J. Rekimoto and Y. Ayatsuka, "CyberCode: Designing Augmented Reality Environments with Visual Tags", Proceedings of DARE 2000, Elsinore, pp. 1-10.

[14] G. Retscher, "Diskussion der Leistungsmerkmale von Systemen zur Positionsbestimmung mit Mobiltelefonen als Basis für Location Based Services (LBS)", in: F. Kelnhofer, M .Lechthaler and K. Brunner (eds.); "Geowissenschaftliche Mitteilungen", Schriftenreihe der Studienrichtung Vermessungswesen und Geoinformation, TU Wien, No. 58, pp. 41-58, 2002 (German).

[15] G. Retscher and M. Thienelt, "NAVIO – A Navigation and Guidance Service for Pedestrians", Journal of Global Positioning Systems, CPGPS, Vol. 3, No. 1-2, pp. 208-217, see http://www.gmat.unsw.edu.au/wang/jgps/v3n12/v3n12p26.pdf (last date accessed: March 2006).

[16] G. Retscher, "A Knowledge-based Kalman Filter Approach for an Intelligent Pedestrian Navigation System", Proceedings of the ION GNSS 2005 Conference, September 13-16, 2005, Long Beach, California, U.S.A. (Institute of Navigation, Fairfax, Virginia), unpaginated CD-ROM.

[17] G. Retscher, "An Intelligent Multi-sensor System for Pedestrian Navigation", Proceedings of the GNSS 2005 Conference, December 8-10, 2005, Hong Kong, PR China, unpaginated CD-ROM.

[18] G. Retscher and M. Thienelt, "Evaluation and Test of a Digital Compass Module Employed for Heading Determination in a Pedestrian Navigation System", in A. Grün and H. Kahmen (eds.), "Optical 3-D Measurement Techniques VII", Papers presented at the 7th Conference on Optical 3-D Measurement Techniques, October 3-5, 2005, Vienna, Austria, pp. 389-394.

[19] G. Retscher, "3-D Position Determination in a Multi-storey Building Using a Pedestrian Navigation System", in: G. Gartner (Ed.), "Geowissenschaftliche Mitteilungen", Schriftenreihe der Studienrichtung Vermessungswesen und Geoinformation, TU Wien, No. 74, Papers presented at the 3rd Symposium on Location Based Services and Telecartography, November 28-30, 2005, Vienna, Austria, pp. 81-86.

[20] G. Retscher, E. Moser, D. Vredeveld and D. Heberling, "Performance and Accuracy Test of the WLAN Indoor Positioning System 'ipos'", Paper presented at the WPNC'06 Workshop at Hannover, Germany, March

16, 2006, Hannoversche Beiträge zur Nachrichtentechnik, No. 0.3, Shaker Verlag, 2006, pp. 7-15.

[21] G. Retscher and M. Kistenich, “Vergleich von Systemen zur Positionsbestimmung und Navigation in Gebäuden”, Zeitschrift für Geodäsie, Geoinformation und Landmanagement (ZfV), Vol. 131, No. 1/2006, pp. 25-35 (German).

[22] J. Roth, “Data Collection”, in: J. Schiller and A. Voisard (Eds.), “Location-Based Services”, Morgan Kaufmann Publishers, USA, 2004, pp. 175-205.

[23] M. Thienelt, A. Eichhorn and A. Reiterer, “Konzept eines wissensbasierten Kalman-Filters für die Fußgängerortung (WiKaF)”, VGI, Österreichische Zeitschrift für Vermessung und Geoinformation, Vol. 93, No. 2, pp. 96-104 (German).

[24] Vaisala, “PTB220 Digital Barometer”, User’s guide, Vaisala, Finland, 2001, http://www.vaisala.com/businessareas/instruments/servicesupport/userguides/barometricpressure/PTB220%20User%20Guide%20in%20English.pdf (last date accessed: March 2006).

[25] R. Want, A. Hopper, V. Falcao, and J. Gibbson, “The Active Badge Location System”, ACM Transactions on Information Systems, 10(1), 1992, pp. 91-102.

[26] WhereNet, “WhereNet Homepage”, http://www.wherenet.com, (last date accessed: March 2006).