UBIQUITOUS POSITIONING SOLUTIONS FOR PEDESTRIAN NAVIGATION

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KEY WORDS: Pedestrian Navigation Systems, Location-based Services, Ubiquitous Positioning, Indoor Localization Techniques, Active Landmarks, RFID (Radio Frequency Identification)

ABSTRACT:

In a new research project called "Ubiquitous Cartography for Pedestrian Navigation (UCPNAVI)" at the Vienna University of Technolgy we want to explore the capabilities of providing location based information and navigation via a ubiquitous environment to enhance route guiding in smart environments. The hypothesis that ubiquitous cartography, defined as a "technological and social development, made possible by mobile and wireless technologies, that receives, presents, analyses and acts upon map data which is distributed to a user in a remote location", enables customized route guiding with various presentation forms and therefore optimizes the wayfinding process. Smart stations (in terms of active and short-range devices) can substitute or complement traditional positioning and information transmission methods by sending information or coordinates of the station instead of trying to locate the user by a central server-based solutions. Different techniques and sensors will be tested and a knowledge-based multi-sensor fusion model will be developed to enhance location determination in smart environments. In this paper the positioning of a mobile user in indoor and urban environment based on RFID (Radio Frequency Identification) in combination with WLAN (Wireless Local Area Networks) and Dead Reckoning (DR) is investigated. The concept of RFID positioning in different case studies and a simulation study for the integration of RFID with WLAN is presented.

1. INTRODUCTION

Within the last few years navigation systems have started to conquer the market in the Western World. Especially in outdoor environments location-based services play an important role for supporting the wayfinding process. Car drivers have started to trust in the information provided by vehicle navigation systems and even pedestrians are gaining interest in reliable guiding instructions. In pedestrian navigation, however, in many cases localization accuracy is insufficient for pedestrian's needs and route suggestions usually rely on road networks and do not meet the demands of walking people, as pedestrians have more degrees of freedom in movement compared to car drivers (Corona and Winter 2001). Moreover, most of navigation systems are limited to outdoor areas, whereas wayfinding within buildings has mostly been neglected so far. Even though the range of some positioning sensors may be sufficient for navigation tasks, they are rarely available within buildings and hardly fulfil the minimum conditions concerning cost (Dempsey, 2003). Because of the expensive infrastructure the user has to expect high costs when using the system. Moreover the communication of 3-D indoor environments on 2-D screens is a difficult task that influences if the user successfully reaches his destination. Guidelines for an effective design of the presentation of indoor environments have not been established so far, yet they are necessary in order to raise user acceptance to a higher level.

Especially in complex buildings, visitors often need guidance and support. One of the main disadvantages inside of buildings affects the sense of orientation: people tend to lose orientation a lot easier within buildings than outdoors (Hohenschuh 2004, Radoczky 2003), especially if not moving along windows. Additionally to navigation support it could be beneficial to supply the user with information that is adapted to the current task. For instance when visiting a shopping centre information about bargains at favoured shops could be displayed, or when strolling around an airport or train station information about departing planes or trains that concern the user could be provided. Instead of passive systems that are installed on the user's device and frequently position them as the user moves along in an indoor environment, new technologies originated in ubiquitous computing could enrich guiding systems by including information captured from an active environment. This would mean that the user is perceived by a ubiquitous environment and receives location based information that is suitable for the respective device or is supplied with helpful notes via a public display or similar presentation tools. Additionally to the function of information transmission poles, these smart stations could possibly substitute or complement traditional indoor positioning methods by sending coordinates of the station instead of locating the user. Based on the concept of Active Landmarks, which actively search for the user and build up a spontaneous "ad-hoc network" via an air-interface, a ubiquitous solution, where an information exchange between different objects and devices are accomplished, is investigated for the use in navigation.

The concept for an ubiquitous positioning solution enables a revolutionary opportunity for navigation systems of any kind. Within the last few years a lot of research and development has taken place concerning Location-based Services (LBS), which could now be supplemented and expanded with the help of ubiquitous methods, and maybe in the future they could even be replaced. Yet research is still in the early development stage that still meet many new challenges. Positioning and tracking of pedestrians in smart environments function differently from conventional navigation systems, since not only passive systems, that execute positioning on demand, need to be considered. Moreover a combination of active and passive positioning methods should be the basis of a ubiquitous navigation system. Such a multi-sensor system for position determination should therefore be able to include both types of location determination and as a result lead to an improvement of positioning accuracy.

Beside the technical challenges of a ubiquitous system, user friendliness is a major ambition in a new research project called "Ubiquitous Cartography for Pedestrian Navigation (UCPNAVI)" at the Vienna University of Technolgy. Due to the diversity of pedestrian navigation strategies and route choice behaviour the user shows specific preferences and requirements concerning spatial information. The improper usage of ubiquitous systems could easily lead to an overload of impressions. A lot of information that might even be completely independent from each other could overstrain the user and hinder effective information extraction. To avoid this effect the aim of such a system should concentrate on providing information about the environment without overstraining the user. It should supply the navigating person with customized information based on individual mobile behaviour and interests and available facilities in the actual surroundings. At decision points the information should be unmistakably clarified but everywhere else, where guidance is not implicitly necessary, additional information should be provided in an unobtrusive way.

In the research project UCPNAVI the following four work packages are investigated:

- Work Package 1 (Positioning in Ubiquitous Environments) investigates positioning methods in a smart environment in combination with conventional positioning techniques. The optimized position will be sent to the user's device.
- In Work Package 2 (Monitoring the Navigation Behaviour of Pedestrians) typologies will be investigated and based on these findings user profiles will be verified and tested by observing the clients mobility behaviour at certain highly frequented environments.
- Based on the obtained position from WP1 and the user profile from WP2, Work Package 3 (Ubiquitous Cartography) determines and filters out suitable route presentation forms, which could either be provided by the ubiquitous environment or by a passive system on the client of the user.
- Work Package 4 (Proof of Concepts) will investigate the effectiveness of the ascertained results of the previous work packages by clarifying the modified navigation behaviour and route finding success of potential users.

This paper concentrates on the research work in WP 1. In the following the problems and state-of-the-art in positioning for pedestrian navigation in ubiquitous environments will be discussed.

2. STATE-OF-THE-ART IN POSITIONING FOR PEDESTRIAN NAVIGATION

In recent years new technologies and methods for positioning in ubiquitous environments have been developed. Most commonly current navigation systems employ a combination of satellite positioning (GNSS) for absolute position determination and dead reckoning (DR) for relative positioning where the direction of motion or heading and the distance travelled of the user are measured from a given start position. Due to the main limitations of the sensors (i.e., satellite availability in the case of GNSS and large drift rates in the case of DR) other positioning technologies should be employed to augment GNSS and DR positioning. Useable alternative geolocation techniques include cellular phone positioning, the use of WLAN (wireless local area networks), UWB (ultra-wide band), RFID (radio frequency identification), Bluetooth and other systems using infrared, ultrasonic and electromagnetic signals (Retscher, 2005b). Thereby the use of already established wireless infrastructure (e.g. WLAN) for positioning has the advantage that usually no additional and costly hardware installations are required. Some of the systems have been especially developed for indoor applications, but they can also be employed in indoor-to-outdoor and urban environments.

WLAN uses radio signals and is based on a standard defined by the Institute of Electrical and Electronics Engineers (IEEE) (IEEE 802.11 2004). A WLAN network consists of so-called access points (or hot spots) and for location determination the signal strengths of the radio signals from at least one of these access points are measured. The location fix is then obtained with trilateration using measurements to several access points or through fingerprinting where the measured signal strength values are compared with in a database stored signal strength values from calibrated points (Beal, 2003; Imst, 2004; Retscher, 2004). Thereby positioning accuracies of about 1 to 4 m can be usually obtained which has been confirmed in a study conducted in a diploma thesis at our University (Moser, 2006). The system has been installed in our office building of the Vienna University of Technology (Retscher, 2007c).

Ultra wideband (UWB) systems, which exploit bandwidths in excess of 1 GHz, are developed for high speed data transmission that has been standardized in IEEE 802.15.3a. They can be employed for measuring accurate time of arrival (ToA) used for estimation of distance or time difference of arrival (TDoA) used for distance difference estimation of the received signals from several base stations for indoor geolocation applications (Kong et al., 2004; Pahlavan et al., 2002). The achievable positioning accuracies are higher than in the case of WLAN; they are in the range of 0.2 to 1 m at a 67% reliability level for indoor position determination (Kong et al., 2004).

Radio Frequency Identification, or RFID for short, 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 an RFID transceiver (Finkenzeller, 2002). The reader is able to read the stored information of the tag in close proximity. To employ RFID for positioning and tracking of objects, one strategy is to install RFID readers at certain waypoints (e.g. entrances of buildings, storage rooms, shops, etc.) to detecte an object when passing by. For that purpose an RFID tag is attached or incoporated in the obejct. This concept is employed for e.g. theft protection of goods in shops and warehouse management and logistics. A second approach for using RFID in positioning would be to install RFID tags along roads (especially in areas without GPS visibility, e.g. in tunnels, under bridges, etc.) and have a reader and antenna installed in the vehicle. When the vehicle passes by the tag the RFID reader retrieves its ID and other information (e.g. the location) (Chon et al., 2004). In pedestrian navigation another possible application would be to install RFID tags at specific landmarks and if the user passes by he can retrieve the tag information with its location. Then it is known that the user is located in cell around the tag with a radius equal to the maximum read range.

Also Bluetooth, which has been originally developed for short range wireless communication, can be employed for locating mobile devices in a certain cell area that is represented by the range of the device which is typically less than 10 m. As RFID it can also be employed for location determination using active landmarks (Retscher and Kistenich, 2006).

In the area of satellite positioning, further development is carried out for so-called high sensitive GPS (HSGPS) systems that can also work indoors (e.g. in a wooden building, sportcomplex, etc.). The number of satellites available and their geometry, however, limit the performance of these systems and the major error source is the multipath. Performance tests reported by Lachapelle (2004) showed much lower positioning accuracies for indoor satellite positioning than that achieved in open space without obstructions.

Locating of a user on the correct floor of a multi-storey building is another challenging task. For more accurate determination of the user's height an improvement is achieved employing a barometric pressure sensor additionally (Retscher, 2004). Tests have been performed in a diploma thesis at our University (Kistenich, 2005) and could prove that we are able to determine the correct floor of a user in a multi-storey building.

From the above summary can be seen that nowadays a wide range of location technologies are available or in the development stage that can be employed for location determination in ubiquitous environments in location-based services. Further investigation and performance tests of the location techniques and sensors are especially required in this field. Also the integration of suitable location techniques in a complex and changing environment is a very challenging task.

3. POSITIONING IN UBIQUITOUS ENVIRONMENTS

3.1 Overall Goal of the Work Package 1 of UCPNAVI

For navigation and guidance in 3-D space, continuous location determination is required with positioning accuracies on the few meter level or even higher, especially for navigation in buildings in vertical dimension (height) as the user must be located on the correct floor. The specialized research hypothesis of this work package is that a navigation and wayfinding in smart environments is possible and 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 in a new multi-sensor fusion model which makes use of knowledge-based systems.

3.2 Location Determination in Smart Environments Using Different Techniques and Sensors

For the navigation and wayfinding in smart environments the use of RFID (Radio Frequency Identification) for ubiquitous positioning is investigated in the project. 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 an 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, i.e., in the range of 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. Many active tags have practical ranges of tens of metres, and a battery life of up to several years. Their range define a cell in which a data exchange between the tag and the reader is possible. Several tags located in the smart environment can overlap and define certain cells with a radius equal the read range. The method for location determination in a cell is referred to as Cell of Origin (CoO) and the accuracy of position determination is defined by the cell size. 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 (Retscher and Kistenich, 2006).

Navigation systems usually also employ dead reckoning (DR) sensors where the current location of the user is determined using observations of the direction of motion (or heading) and the distance travelled from a known start position. Due to the main limitations of DR sensors, i.e., the large drift rates of the sensors, an absolute position determination is required at certain time intervals to update the DR observations and correct for the sensor drift (Retscher, 2004). The absolute position determination is usually performed with satellite positioning (GPS). RFID positioning can provide this position updates in smart environments where satellite positioning is not available. It is proposed that at least the following DR sensors should be included: an attitude sensor (i.e., a digital compass) giving the orientation and heading in combination with an inertial tracking sensor (e.g. a low-cost Inertial Measurement Unit IMU) including a three-axis accelerometer also employed for travel distance measurements as well as a digital barometric pressure sensor for height determination.

3.3 Sensor Integration Using a Multi-sensor Fusion Model

The integration of different sensors and location methods shall be based on an intelligent multi-sensor fusion model. Thereby the current position of a user is estimated using a Kalman filter approach which makes use of knowledge-based systems. The concept has been developed and is presented in Retscher (2005a) and (2007b). Firstly the observations of each sensor and location technique 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 pre-processing 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). Then the optimal estimate of the user's position should be more based on the observations of other sensors (e.g. DR observations, RFID positioning, etc.).

4. THE USE OF RFID POSITIONING SHOWN IN DIFFERENT CASE STUDIES

In the following the concept for location placement of RFID tags in different indoor environment is shown in three case studies, i.e.,

- a RFID positioning concept for a floor in a large office building,
- a RFID positioning concept for a floor in a large shopping mall and
- a RFID positioning concept for the departure level in an airport.

4.1 RFID Positioning Concept for an Office Building

Figure 1 shows an example for the proposed location of active landmarks equipped with RFID tags on the 3rd floor of our office building at the Vienna University of Technology. In the chosen indoor environment the active RFID tags will be placed at lift entrances and doors to offices, at the staircases at different levels, inside office rooms (e.g. the secretary's office) and the general teaching rooms as well as at regular distances along the corridor.

4.2 RFID Positioning Concept for a Large Shopping Mall

In Figure 2 the concept for location placement of active landmarks equipped with RFID tags in a shopping mall (i.e., the Donauzentrum in Vienna) is shown. The shopping centre has been chosen, as preliminary monitoring of the movement behaviour of shoppers in work package 2 of the UCPNAVI project has been conducted in this shopping mall. The RFID positioning system could be part of an information system for the guidance of shoppers in the mall. It is proposed to have RFID tags located at the entrances to the shopping mall and at the entrances to different shops, as well as inside of large shops, along the corridors and at regular intervalls in the car park.

4.3 RFID Positioning Concept for an Airport

To provide navigation and guidance aid around a complex airport is a challenging task. For this case study the Vienna Internationational Airport has been selected as test site. The departure level of the airport is shown in Figure 3. It is divided into three different gate areas, i.e., gates A on pier east for international flights and gates B (bus gates) and C (pier west) for domestic and European Union flights. As an example,

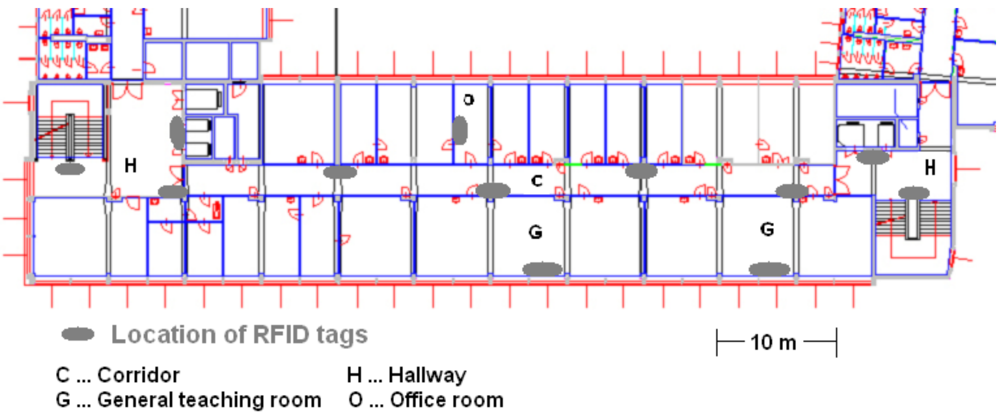

Figure 1. Concept for location placement of active landmarks equipped with RFID tags in an office building (3rd floor of our office building at the Vienna University of Technology)

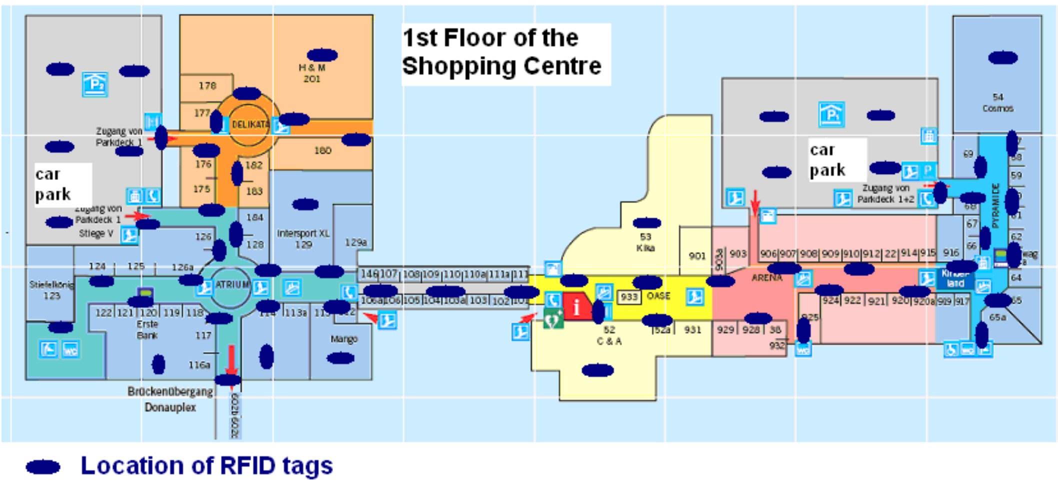

Figure 2. Concept for location placement of active landmarks equipped with RFID tags in a shopping mall (1st floor of the shopping mall Donauzentrum[1] in Vienna)

[1] Website of the Shopping Centre Donauzentrum: http://www.donauzentrum.at/

Figure 4 shows the proposed location of RFID tags in the gate areas of pier west and the connecting corridor to the terminals. The tags are placed at the entrances to the gates, as well as at shop entrances and airline lounges and at regular distances along the corridor between the gates and the terminal.

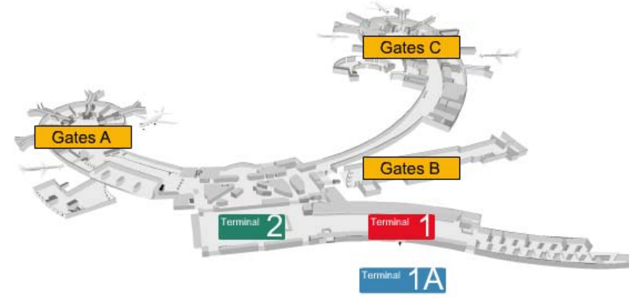

Figure 3. Departure level of the Vienna International Airport[2]

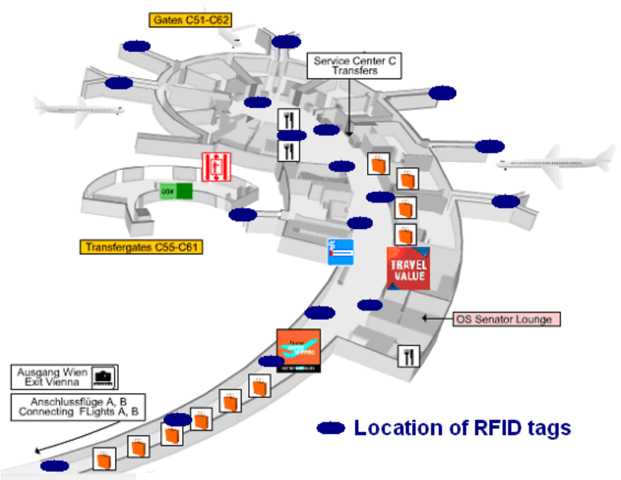

Figure 4. Concept for location placement of active landmarks equipped with RFID tags in an airport (departure level of the Vienna International Airport)

4.4 RFID Equipment Requirements

To perform a meaningful cell-based positioning using RFID the read range of the tags should be several metres. Therefore it is required to employ active tags. We propose to use wireless long-range RFID systems from Identec Solutions for the positioning of a pedestrian in the case studies. Using the Intelligent Long Range® (ILR®) technique, the user can be located at a distance of up to 100 m (Identec Solutions, 2006). Higher positioning accuracies can be achieved by reducing the sensitivity in the reader. It is therefore possible to limit the read range down to a few meters. Then the RFID positioning can be used if no GNSS positioning is available due to satellite signal obstructions in urban areas and in the transition area from outdoor to indoor environment or if no other location method (such as WLAN) is available in the indoor environment.

5. INTEGRATION OF RFID POSTIONING WITH OTHER INDOOR LOCATION TECHNIQUES

In the localization testbed at the Vienna University of Technology (see section 4.1, Figure 1) also WLAN is available. For the positioning using WLAN a software package called 'ipos' developed by IMST GmbH is employed (Imst, 2004). For software testing and analysis a cooperation between our University Institute and IMST GmbH was established. The software ipos is based on the fingerprinting method (see section 1) which requires signal strenght observations at known locations inside the building in an offline phase. This values are stored in a database and used in the online phase to obtain an optimal estimate of the current user's position. The system makes use of the already installed access points for wireless communication in our office building. As the ipos positioning system is a software solution which runs on the mobile device (e.g. a notebook computer or pocket PC) or a server in the network, standard WLAN hardware without any modifications can be used. Recent performance tests have been conducted in the localization testbed at our University and their main results are reported in Retscher (2007c). In the tests it could be seen that the expected positioning accuracy in the range of ± 1 to 4 m can be achieved in most cases inside the building. In the following, a combination of WLAN and RFID positioning in the localization testbed of our University will be discussed.

As in some areas in the localization testbed the achievable positioning accuracies are lower than expected or a positioning is not possible at all (e.g. at the boundaries of the covered area), a combination with RFID might be useful. Reasons for lower accuracies are that in some areas a system calibration in the offline phase was not possible due to the fact that either this area was not accessible or the signal strenghts of the WLAN signals from the chosen five access points were not sufficient. To analyse the WLAN coverage and the achievable positioning accuracies in the testbed a simulation using image processing was performed. For that purpose a simulation software called 'Kingston' was developed that uses the ipos database with the signal strength values of the surrounding access points at certain locations inside the building obtained during the calibration in the offline phase. Figure 5 shows a visualization of the WLAN coverage and achievable positioning accuracy in the localization testbed. The pixel colour intensity in the image reflects the signal strength and the positioning accuracy on that particular location.

Using this simulation tool it is now possible to determine if either additional WLAN access points or active landmarks equipped with RFID tags are needed. As an example, Figure 6 shows two locations for proposed RFID tags where one is located in the main staircase on the left and the second in an office room on the right. Based on the simulation tool it is possible to decide how the WLAN positioning system can be augmented meaningful by using RFID. As can be seen, using a combined indoor locating system integrating WLAN and RFID, the areas providing good positioning accuracy in the testbed can therefore be increased significantly.

[2] Website of the Vienna International Airport: http://www.viennaairport.com/

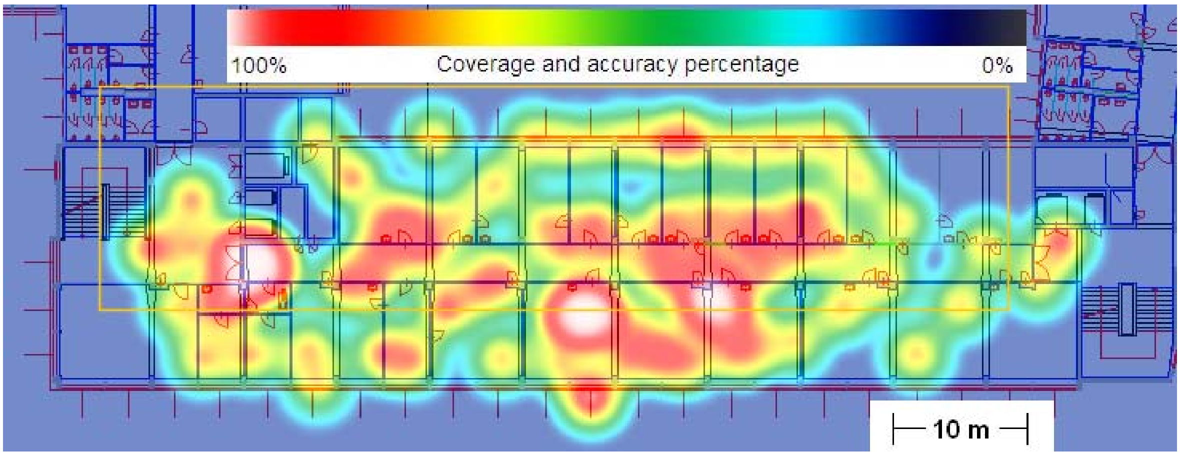

Figure 5. Visualization of the WLAN coverage and achievable positioning accuracy in the localization testbed

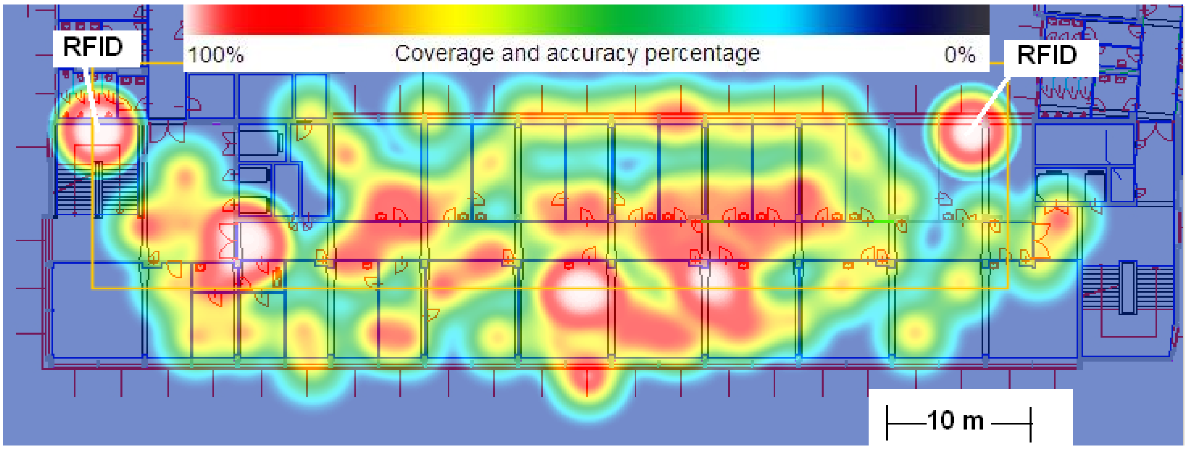

Figure 6. Visualization of the augmentation with two active landmarks equipped with RFID tags

6. CONCLUDING REMARKS AND OUTLOOK

In the research project UCPNAVI the positioning in ubiquitous environments is investigated. In a first step appropiate sensors and location methods in smart environments have been analysed and tested to obtain evidence about their suitability, reliability and accuracy potential. Thereby the investigation is concentrated on the performance evaluation of RFID positioning in combination with WLAN and dead reckoning (DR) sensors in indoor environments. Using the absolute position from WLAN or RFID it is then possible to correct for the drift rates of the DR sensors. In transition areas to outdoor and in urban environments also an integration of RFID, GNSS and DR is investigated. For the integrated position determination using all available sensor observations, a multi-sensor fusion model based on a Kalman filter approach which makes use of knowledge-based systems has to be implemented and a software package will be developed. The software package will be tested and analyzed using simulated observation data and data from the sensor tests. The test sites will cover both outdoor and indoor areas under different conditions, including transition from indoor to outdoor (and vice versa). The feedbacks of the tests will be taken into account in system refinement.

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8. BIOGRAPHICAL NOTES

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9. ACKNOWLEDGEMENTS

Part of the research work presented in this paper is supported by the FWF Project UCPNAVI (Project No. P19210-N15) of the Austrian Science Foundation (FwF Fonds zur Förderung wissenschaftlicher Forschung).
The WiFi positioning system 'ipos' was kindly provided by the German company IMST GmbH (http://www.imst.de/).
The author would like to thank also the students of the practical course on location-based services in the winter term 2006/07 for the performance of the WLAN positioning tests in our office building and Mr. Johan Liesén for his help in the development of the simulation tool 'Kingston'.