Investigations of selected systems for Indoor and Pedestrian Navigation

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Abstract

Within the last decade navigation systems have become popular. Vehicle drivers have started to trust in the information provided by car navigation systems and even pedestrians are gaining interest in reliable guiding instructions. Most of the available systems on the market, however, are limited to outdoor areas, whereas way-finding within buildings has mostly been neglected so far as location systems are rarely available indoors. In a conducted performance analysis of indoor location systems could be also seen that the user has to expect high costs in using some of these systems (e.g. using infrared and ultrasonic signals) as an installation of a large number of sensors is required in the building. One approach to reduce costs is the use of already available wireless infrastructure such as Wireless Local Area Networks (WLAN). Such a positioning system has been installed in an office building of the Vienna University of Technology and can be employed for location determination of user's which are equipped with a WLAN enabled mobile device. In addition, the use of Radio Frequency Identification (RFID) tags at selected known points, so-called active landmarks, is currently investigated. Then the user can be located using cell-based positioning if he is in the read range of such a tag. Currently the deployment of such a concept in our office building and in the surrounding outdoor environment is investigated. Furthermore a combination with WLAN and dead reckoning shall be performed in the near future to provide continuous position determination of a user.

Kurzfassung

Der Einsatz von Navigationssystemen hat vor allem im letzten Jahrzehnt sehr stark an Popularität gewonnen. Autofahrer vertrauen immer mehr auf die Führungsanweisungen von Autonavigationssystemen und auch Fußgänger nutzen moderne, mobile Systeme. Die meisten am Markt befindlichen Systeme können jedoch nur im Freien genutzt werden, da sie im wesentlichen auf satellitengestützter Positionierung beruhen und die Positionsbestimmung in komplexen Gebäuden vernachlässigt wird. Zur Positionierung in Gebäuden wurden in den letzten Jahren eigene Systeme entwickelt, die z.B. Infrarot, Ultraschall oder Radiosignale sowie digitale Kameras nutzen. Sie stehen jedoch zur Lokalisierung von Personen und Objekten in komplexen, öffentlichen Bürogebäuden und anderen wichtigen Einrichtungen (wie Einkaufszentren, Bahnhöfen, Flughäfen, usw.) kaum zur Verfügung und einige dieser Systeme erfüllen im Hinblick auf die hohen Kosten für die notwendige Installation von Sensoren im Gebäude kaum die Erwartungen der Nutzer. Eine Strategie zur Reduzierung der notwendigen Installationskosten besteht darin, bereits im Gebäude vorhandene Infrastruktur, wie z.B. Wireless Local Area Networks (WLAN), zur Positionierung zu nutzen. Ein solches Positionierungssystem steht nun in unserem Bürogebäude der Technischen Universität Wien zur Verfügung und kann zur Lokalisierung von Nutzern mit einem mobilen, WLAN-fähigen Notebook oder Pocket-PC verwendet werden. Mit diesem System kann man einen Nutzer mit einer durchschnittlichen Genauigkeit von ± 1 bis 4 m positionieren, womit man in der Regel in der Lage ist, den Büroraum anzugeben, in dem sich der Nutzer gerade befindet, bzw. eine kontinuierliche Positionsbestimmung und Zielführung bei einem sich bewegenden Nutzer durchzuführen. Zusätzlich wird nun der Einsatz der Radio Frequency Identification (RFID) Technologie zur Positionierung in Gebäuden und städtischen Umfeld untersucht, wobei die RFID-Tags an ausgewählten, bekannten Punkten, den sog. Active Landmarks, angebracht werden. Der Nutzer kann dann mit Hilfe einer zellbasierten Positionierungsmethode lokalisiert werden, wenn er sich im Empfangsbereich von einem RFID-Tag befindet und ein RFID Lesegerät (z.B. in PC-Kartenformat) verwendet. Zur Zeit bereiten wir die Installation eines solchen Positionierungssystems in unserem Bürogebäude und der umliegenden, urbanen Umgebung vor. Weiters soll in Zukunft eine Kombination mit WLAN und der Koppelnavigation untersucht und verwirklicht werden.

1. Introduction and Overview about Previously Conducted and Current Research at our University

Personal mobility and location-based services have been identified as main research areas in recent years. Most developments have started with emerging navigation and tracking systems in the area of vehicle guidance in the early 1980's. The avaiability of GPS receivers has significantly changed the navigation market and their integration with other existing techniques has become a common integration scenario.

Nowadays mainly multi-sensor solutions are employed as satellite positioning does not work in every environment, e.g. in urban canyons where satellite signals are frequently blocked or positioning accuracies are low due to a weak reveiver-satellite geometry (i.e., high DOP (Dilution of Precision)). Based on these developments the author started to work on the improvement of location techniques for personal navigation about a decade ago. In a first study emerging vehicle navigation systems on the European market have been analyzed and the integration of GPS and dead reckoning in future intelligent vehicle navigation systems (IVNS) has been discussed. In the following, the use of alternative location techniques, e.g. the integration of cellular phone positioning into vehicle navigation systems was investigated. Part of the work was carried out in a joint research project [1)] with the Department of Land Surveying and Geo-Informatics of the Hong Kong Polytechnic University (see [10]).

Apart from navigation systems for vehicles research efforts have been concentrated on the challenging task of location determination for pedestrians in recent years (see e.g. [5], [12]). In the work package 'Integrated Positioning' of the research project NAVIO [2)] at the Vienna University of Techology different aspects of location determination of a pedestrian in a combined indoor and outdoor urban environment have been investigated. Before the start of the project a study was conducted to investigate the possible sensors that are suitable to be integrated in a pedestrian navigation system. It was found that a pedestrian navigation system should include at least a GPS receiver for absolute position determination and dead reckoning (DR) sensors for relative positioning such as a heading sensor and accelerometers for measurement of the direction of motion and the distance travelled as well as a barometric pressure sensor for altitude determination [18]. A multi-sensor system has been developed in NAVIO and first tests of the integrated location sensors were presented in [16]. For the integration of all available sensor observations a new multi-sensor fusion model that makes use of knowledge-based systems was developed (see section 5).

The provision of navigation and guidance services in challenging indoor environments (e.g. in large office buildings, shopping centres, railway stations, airports, etc.) is very important; especially in the case of emergency situations (e.g. to locate firefighters in a rescue situation inside a building). New developments in indoor location techniques have been investigated and their principle of operation, application and performance was analyzed (see [8]). Systems available on the market use signals such as infrared, ultrasonic and radio signals. Most of these systems, however, require expensive installations of a larger number of receivers or transmitters in the indoor environment. To reduce installation costs an approach was choosen which makes use of already available infrastructure, i.e., the use of Wireless LAN (WLAN or WiFi) [1].

At the Vienna University of Technology a location system based on WLAN has just been installed recently in our office building. For that purpose a cooperation with the German research institute IMST GmbH [3)] has been established. The WLAN location system 'ipos' is jointly analyzed and further improvements will be made to the system design. A performance test of the system ipos is presented in section 2. Apart from WLAN also other techniques, such as Ultra Wide Band (UWB) [9], [20] and RFID [2], [17] are currently investigated in more detail and their integration into the system design of a pedestrian navigation system is analyzed. The main advantage of the new wireless radio signals in the UWB band will be the improved performance and accuracy compared to the current WLAN standard. Using these signals positioning accuracies on the dm-level can be achieved in the future. If positioning accuracy requirements are not so high then RFID will be a cheap alternative to perform cell-based positioning. If a user is in the read range of an RFID tag which is placed at a known location (so-called active landmark) then he can retrieve the tags information with its current location. The mobile user has to carry only a reader which can be in the form of a PC card and plugged into a mobile device (e.g. a pocket PC). This form of positioning can be applied also to augement GNSS positioning in areas with no satellite visibilty (e.g. in tunnels, under bridges, etc.) in vehicle navigation. For indoor location determination a concept has already been developed (see section 3). System testing will be performed in a localization testbed at the Vienna University of Technology at our department. In the following, first the performance of the WLAN system ipos and then the concept of RFID positioning will be discussed in more detail.

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1) Research project B.34.37.Q329 "A satellite based multi-sensor system for intelligent land vehicle navigation and tracking system suitable in a dense high-rise environment" founded by the Research Grants Council RGC of the Hong Kong SAR Government, PR China.

2) Research project P16277-N04 "Pedestrian Navigation Systems in Combined Indoor/Outdoor Environments" founded by the Austrian Science Funds (Fonds zur Förderung wissenschaftlicher Forschung FWF).

3) System 'ipos' of IMST GmbH, Kamp-Lintfort, Germany, see also http://www.centrum21.de/.

2. Performance of the WLAN Indoor Positioning System ipos

A common approach for the localization of a mobile device by means of WLAN (or WiFi) is based on measurements of received signal strengths of the WLAN signals from surrounding access points at the terminal [1]. 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 from modelling of the surrounding environment or with prior calibration measurements at certain locations. In the first case, a building model is used to estimate the signal propagation of the radio signals from all available access points; whereas in the second case, the signal strengths are measured at certain known locations in the building. Using the second approach higher positioning accuracies can be obtained as it is based on actual measurements of signal strength values. The calculation of the location of a user takes place in two phases: an offline and an online phase. During the offline phase (i.e., the calibration), which has to be executed only once for each building, a so-called radiomap will be composed. This radiomap can be considered to be a collection of calibration points at different locations in the building, each with a list of radio signal strength indicator (RSSI) values for visible access points at that particular location. This process is also known as fingerprinting. During the online phase, the calibration points are being used to calculate the most probable location of the user, whose actual location is unknown. Further information about the principle of operation of the WLAN positioning system 'ipos' can be found in [15].

In a first study the performance of the WLAN positioning system ipos was analyzed in an office building of IMST GmbH in Germany in a diploma thesis (see [11]). In the tests different scenarios were investigated; e.g. if a standing or moving user can be located in an office room or a predefined area and when he is moving from one office room to another along the corridor. The expected positioning accuracy in the range of ± 1 to 4 m could be confirmed in the tests in most cases. The system is now available in our office building of the Vienna University of Technolgy and makes use of the already installed access points for wireless communication. As the ipos positioning system is a software solution which runs on the mobile device or a server in the network, standard WLAN hardware without any modifications can be used. Recent performance tests have been conducted and their main results are summarized in the following.

For the performance tests the office rooms and corridor between two staircases on the 3rd floor of our building have been selected (see Figure 1). In every office room (with a size of around 19.5 m^2) at least 2 calibration points are located, in the two general teaching rooms which have a size of around 110 m^2 around 10 calibration points and along the cooridor 15 calibration points were positioned. Along the corridor there are three WLAN access points evenly distributed. Apart from those, also the signals of two additional access points located on other levels in the building have been used in the test. Figure 1 shows the location of the test points for a standing user and a classification of the deviations of the position fixes from the selected 'true' location. A few test points along the corridor, in office rooms and the general teaching rooms have been selected. On every test point position fixes were determined over several minutes with a frequency of 1 Hz. The deviations of the position fixes from the truth were in the range of 0 to 3 m for most of the points. As an example, Figure 2 shows the location of around 250 position fixes on one point which is located in the hallway in front of the elevator (i.e., point 1 in Figure 1) in a local coordinate system (where the Y-axis is parallel to the main axis of the building tract; note that many position fixes in Figure 2 have the same location). The standard deviation of the position fixes in the X-coordinates resulted in ± 0.3 m and in Y-coordinates in ± 1.0 m. Remarkable is that the position fixes show a significant systematic offset from the true location (X=111.39 m, Y=109.63 m) where the deviation of the mean value of all position fixes from the true location is 2.1 m. In respective to the location of the mean value, 67.2 % of the individual position fixes have a smaller Y-coordinate than the mean value (i.e., Y=110.26 m) and only 32.8 % have a larger value for the Y-coordinate. In the X-coordinates 46 % of all position fixes have a larger value and 54 % a smaller value than the X-coordinate of the mean value (i.e., X=109.35 m). The mean positional error of all position fixes on point 1 in relation to the truth is ± 2.9 m.

Figure 3 shows the track of a moving user from the start point in the hallway in front of the elevator to the general teaching room. The reference track is shown in green and the track of the moving user in light blue. The deviations from the reference track are in the range of 1 to 4 m. As can be seen from Figure 3, the reference track is followed quite nicely along the corridor where the deviations are less than 1.3 m. The largest deviations occurred at the end of the track as the user entered the general teaching room. The higher positioning accuracies along the corridor is due to the larger number of calibration points. The number of calibration points in the general teaching room seems not to be sufficient and should be increased. In the example, the track crosses also the wall between the corridor and the room and reaches a maximum deviation inside the room of around 4 m. In this case, an improvement of the solution can be achieved if the building map is used in a post-processing step which does not allow the track of the user to cross walls when there is no door between them. Then the crossing of the wall can be matched to the nearest door between the corridor and the room.

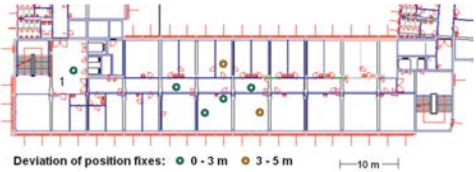

Figure 1: Location of the test points for a standing user in the localization testbed (i.e., 3rd floor of our office building of the Vienna University of Technology) showing a classification of the deviations of the position fixes from the selected 'true' location.

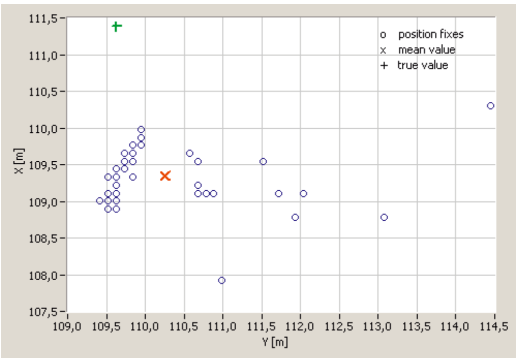

Figure 2: Location of the position fixes for point 1 in the hallway in front of the elevator in respective to its true location.

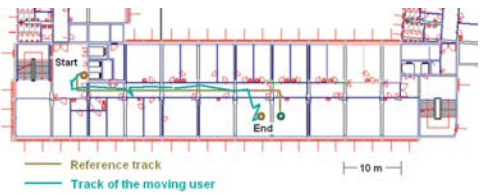

Figure 3: Track of a moving user from the elevator in the hallway to the general teaching room.

3. RFID Positioning and Active Landmarks

Apart from WiFi fingerprinting for indoor location determination the use of RFID for positioning (see [2], [17]) using active landmarks is planned to augment the indoor location determination in araes which are not covered with WLAN. RFID relies on storing and remotely retrieving data using devices called RFID transponders. Typical RFID systems consist of transponders (called tags) with antennas and transceivers (called readers). RFID tags contain silicon chips and antennas to enable them to receive and respond to radio-frequency queries from a RFID reader. RFID tags can be either active, semi-active or passive. Passive tags require no internal power supply, whereas active tags require a power source. The passive tags do have, however, a smaller read range than active tags, i.e., in the range of about 2 mm up to several metres depending on the chosen radio frequency. On the other hand, long range active tags with their own power supply could have a read range of up to 100 m. Another advantage is that active tags have larger memories than passive tags and the ability to store additional information (apart from the tag ID). At present, the smallest active tags are about the size of a coin. Further information about the underlying technology can be found in [3].

For indoor and outdoor pedestrian location determination we propose that RFID tags are installed at known locations in the surrounding environment (so-called active landmarks, at e.g. street crossings, entrances of buildings and offices, at regular distances inside of buildings, etc.). The system user would be equipped with a portable RFID reader module. If the tag's information can be retrieved the user is located in a cell of circular shape with the location of the tag in the centre and a radius equal to the possible read range of the tag. The used location method is referred to as Cell of Origin (CoO) [7]. Several tags located in the smart environment can overlap and define certain cells that intersect. The position of the user can therefore be determined using the network of the tags which can be made available in a database. Figure 4 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. We propose to use wireless long-range RFID systems from Identec Solutions for the positioning of a pedestrian in the localization testbed. Using the Intelligent Long Range® (ILR®) technique, the user can be located at a distance of up to 100 m [6]. 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 in the presence of an active landmark the RFID positioning can be used if no GNSS positioning is available due to satellite signal obstructions in urban areas or no WLAN positioning is possible in the indoor environment. The research in this field is conducted in a new research project [4]. In the following section a combination of WLAN and RFID positioning in the localization testbed of our University will be discussed.

Figure 4: Concept for location placement of active landmarks equipped with RFID tags in the localization testbed.

4. Augmentation of WLAN Positioning with RFID

The performance tests of the WLAN positioning ipos presented in section 2 have also shown that in some areas in the localization testbed the achievable positioning accuracies are lower than usual or that a positioning is not possible at all (e.g. at the boundaries of the covered area). In this areas a calibration 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. A high level of signal strengths to all visible access points results directly in a good positioning accuracy. Using this simulation tool it is now possible to determine if either additional WLAN access points or active land-marks equipped with RFID tags are needed. As an example, Figure 5 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. In simulating the cell-based positioning an isotropic distribution of the range of the RFID system was assumed. The degradiation of the signal strength due to walls, however, was not modelled and has been neglected in this simulation. Based on the simulation tool it is possible to decide how the WLAN positioning system can be augmented meaningful by using RFID. Using a combined indoor location system integrating WLAN and RFID, the areas providing good positioning accuracy in the testbed can therefore be increased significantly.

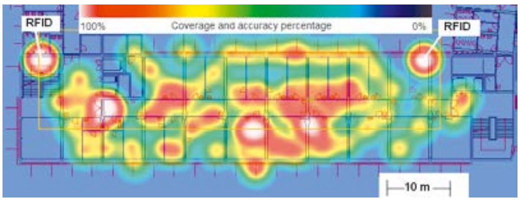

Figure 5: Visualization of the WLAN coverage and achievable positioning accuracy in the localization testbed and augmentation with two active landmarks equipped with RFID tags.

5. Integration with Dead Reckoning (DR) Sensors

In the work package 'Integrated Positioning' of the research project NAVIO[2] a pedestrian navigation system has been developed in recent years (see e.g. [13]). In the system dead reckoning sensors are employed for relative position determination from a given start position and GPS is employed for absolute positioning. Using such a multi-sensor approach the current user's position and the distance travelled, the direction of motion and the changes in altitude can be determined. For the integration of all sensor observations a new fusion model based on knowledge-based systems has been developed ([14], [19]). The approach makes use of a knowledge-based component for a

4) Research project P19210-N15 "Ubiquitous Cartography for Pedestrian Navigation UCPNAVI" founded by the Austrian Science Funds (Fonds zur Förderung wissenschaftlicher Forschung FWF).

preprocessing of all available sensor observations. In this preprocessing step outliers and large errors are detected and these observations discarded as well as the quality of the new observations analyzed before their integration in a centralized Kalman filter (see [4]). Then the knowledge about the quality of the current observations from the preprocessing filter can be used to adapt the stochastic Kalman filter model; for example, in the case of large observation errors their weighting can be considerably reduced in the filter. The optimal estimate of the current user's position is then obtained in the filter process. The performance of the NAVIO system has been tested in different site conditions (e.g. sites providing free satellite visibility and in urban areas where satellite signals are frequently blocked). Major test results have been reported in [13]. Using the new multi-sensor fusion approach a high reliabilty and location accuracy for continuous position determination of a pedestrian in urban environments was achieved. In general, it could be shown that a user can be located continuously in outdoor urban environments with a positioning accuracy of a few metres. A next development step deals with the positioning of a user in indoor environment. For that purpose the dead reckoning observations will be augmented with WLAN and RFID positioning if this systems are available. Using the absolute position from WLAN or RFID it is then possible to correct for the drift rates of the DR sensors.

6. Concluding Remarks and Outlook

One might think that a lot has been achieved already in terms of positioning accuracy and system performance in the field of personal navigation and location-based services. The acceptance by the public, however, does not depend only on the achievable location accuracy but also on the reliability of continuous position determination and the integrity of the systems. The author believes that still a lot has to be done in this field of research and he will continue his work in this challenging area. Especially the upcoming introduction of the GALILIEO system will play an important role in navigation applications and if it will be augmented by alternative techniques and location sensors as shown by the author in the presented work the reliability of the continuous position determination can be significantly increased. This will help to improve the acceptance by the user who tries to find his way in an unfamiliar environment no matter if it will be in an urban or a combined indoor/outdoor environment.

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