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Ubiquitous Positioning Technologies for Modern Intelligent Navigation Systems

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Recently new location technologies have emerged that can be employed in modern advanced navigation systems. They can be employed to augment Global Navigation Satellite System (GNSS) positioning techniques and dead reckoning as they offer different levels of positioning accuracies and performance. An integration of other technologies is especially required in indoor and outdoor-to-indoor environments. The paper gives an overview of the newly developed ubiquitous positioning technologies and their integration in navigation systems. Furthermore two case studies are presented, i.e., the improvement of land vehicle safety using Augmented Reality (AR) technologies and pedestrian navigation services for the guidance of users to certain University offices. In the first case study the integration of map matching into a Kalman filter approach is performed (referred to as "Intelligent Vehicle Navigation") and its principle is briefly described. This approach can also be adapted for the pedestrian navigation service described in the second case study.

KEY WORDS

1. Ubiquitous Positioning. 2. Intelligent Vehicle Navigation. 3. Pedestrian Navigation. 4. Augmented Reality.

1. INTRODUCTION.

The integration of different location technologies and sensors is viable for the performance of modern advanced navigation systems. Thereby common navigation systems rely mainly on satellite positioning (GNSS) for absolute position determination. Losses of lock of satellite signals are usually bridged using dead reckoning (DR) measurements. 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 integrated into the system design of a personal navigation system to augment GNSS and DR positioning. In particular navigation in urban areas is a very challenging task as the user moves in general in areas where no one of the common location techniques works continuously in standalone mode. To solve this challenging task of continuous position determination, a combination with other location techniques is required. The paper reviews current positioning technologies that can be employed in navigation systems. Useable alternative geolocation techniques include cellular phone positioning, the use of wireless local area networks (WLAN), ultra-wide band (UWB), radio frequency identification (RFID) and Bluetooth for location determination.

In the development of wireless geolocation techniques two basic approaches can be distinguished, i.e., one approach where the system is solely designed for positioning using certain radio signals and the second where already established wireless infrastructure (e.g. WLAN) is employed for location determination (Pahlavan et al. 2002). Thereby the second approach has the advantage that usually no additional and costly hardware installations are required. Some of these systems have been especially developed for indoor applications, but they can also be employed in indoor-to-outdoor and urban environments. The concepts of these geolocation techniques are described in the paper.

The integration of the sensors and location techniques is usually performed using a Kalman filter approach. In vehicle navigation systems the resulting trajectory is then matched to a digital road map. Spatial information databases containing the road network are in general a standard component of many mobile navigation systems. This is directly due to their ability to provide detailed information about the location and inter-relationship of geographically defined features. The common map matching techniques traditionally use this information in an attempt to improve navigation accuracy. In a research project conducted at the University of Melbourne the integration of map matching techniques within the Kalman filter like other navigation sensors such as GPS, gyroscopes, odometers, etc. was proposed as a means of providing additional measurements that can be used to improve position and attitude determination (Kealy and Scott-Young 2004). This approach has been termed "Intelligent Vehicle Navigation" and its principle will be described briefly in the paper.

The intelligent vehicle navigation approach has been employed in a case study for the determination of position and attitude of a vehicle for improving land vehicle safety using Augmented Reality (AR) technologies. This research has demonstrated the potential of integrated positioning systems to provide the necessary outputs of position and attitude to support real-time AR applications. AR systems have been identified in many areas as holding enormous promise to enhance human management of complex systems. Key to the effectiveness of AR systems is the performance of the integrated positioning system, as this establishes the accuracy to which virtual objects can be aligned with the real world. In the case study a multi-antenna array of dual frequency GPS receivers, a fibre optic gyro and vehicle odometer have been integrated with real-time imagery containing augmented objects to improve a driver's ability to 'see' the road and surrounding vehicles despite poor visibility conditions (Kealy et al. 2004).

Furthermore in a second case study the navigation of pedestrians in combined urban and indoor environments is presented in this paper. In the research project NAVIO (Pedestrian **Nav**igation Systems in Combined **I**ndoor/**O**utdoor Environments) the guidance of visitors to departments and persons of the Vienna University of Techology is investigated (Retscher 2004). Thereby a navigation system is employed which integrates several different sensors and location techniques, i.e., GNSS and indoor location techniques, cellular phone positioning, dead reckoning sensors (e.g. magnetic compass, gyro and accelerometers) for measurement of heading and distance travelled as well as barometric pressure sensors for height determination. The results of simulation studies and practical tests could confirm that such a service can achieve a high level of performance for the guidance of a pedestrian in urban areas and mixed indoor and outdoor environments (Retscher and Thienelt 2004).

2. REVIEW OF POSITIONING TECHNOLOGIES USED IN NAVIGATION.

For location determination of cellular phones or other mobile devices advanced positioning methods have been developed based on measurements using the signals of the wireless network. Most of them are based on classical terrestrial navigation methods where at least two observations to different base transmitting stations (BTS) are required to obtain a 2-D position fix (see e.g. Balbach 2000, Drane et al. 1998, Hein et al. 2000, Retscher 2002). The achievable positioning accuracy thereby depends mainly on the location method and type of wireless network (GSM, W-CDMA, UMTS). Thereby the most accurate location method is the so-called Enhanced Observed Time Difference (E-OTD) method where the position fix is obtained from the measurements of time differences of signals sent from at least three BTS at the mobile station (MS) and a reference station in the network which is referred to as Location Measurement Unit (LMU). Using E-OTD the achievable positioning accuracy ranges between 50 to 150 m for urban areas. As advanced and more accurate methods, such as E-OTD, however, require modification of the network as well as installation of additional hardware and one LMU for every 3 to 5 serving BTS's, they have not been widely deployed yet in wireless networks around the world. Useable location-based services therefore rely mostly on cell positioning (i.e., Cell ID) which provides only positioning accuracies on the 150 m to 1 km level in urban areas and up to 35 km in rural areas. Recent developments have therefore been concentrated on the reduction of network modification for advanced positioning. The so-called Matrix method (Duffett-Smith and Craig 2004) does not need any additional hardware in the network apart from a SMLC (Serving Mobile Location Centre) where the location determination of the mobile handset is performed. The standard matrix method is based on E-OTD that does not require any LMU's. In this case a software upgrade is installed in the MS and the terminal measures the relative receive times of the signals from surrounding network transmitters (BTS). These timings are occasionally requested by the matrix SMLC from "anonymous" terminals and are used to calculate and maintain a list of network transmission offsets (the so-called network timings). When a position request for a specified MS is generated by an application, the terminal responds with its timing measurements which the matrix locator then uses in conjunction with the network timings to calculate the position of the MS. Standard matrix systems have been tested around the world in different wireless networks and achieve a positioning accuracy of 50 to 100 m at the 67% reliability level in the GSM network. The positioning can also be performed using only one MS as the measurements for obtaining the network timings need not to be simultaneous. Measurements at different times of one moving MS can be used instead of measurements from anonymous terminals. These are used to maintain the network timing model and the current measurement is used to calculate that location. In fact, the previous and current measurements can also be used in a single calculation to calculate all locations and hence to obtain the track of the moving MS. This method is also referred to as Solo Matrix and if it is embedded into the MS and combined with satellite positioning (GPS) the term Enhanced GPS (E-GPS) is used. Then the solo matrix can provide assistance data such as initial position and reference time for the GPS positioning as in the case of Assisted GPS (A-GPS).

Apart from cellular networks, wireless LAN have become popular in recent years. WLAN uses radio signals and is based on a standard defined by the Institute of Electrical and Electronics Engineers (IEEE) (IEEE 802.11 2004). Thereby a WLAN network consists of so-called access points (or hotspots) 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). As the indoor radio channel suffers from severe multipath propagation and heavy shadow fading, the fingerprint method achieves higher positioning accuracies than trilateration. Positioning accuracies of about 1 to 3 m could be obtained in a test office building using the fingerprint WLAN positioning system ipos of the German company Imst (2004). The positioning system ipos makes use of a standard WLAN infrastructure and no modification of the hardware is required. The location determination of the mobile users is performed on a server in the network where the database of the signal strength values of the calibrated points is accessible. The database of the signal strength values has to be obtained using calibration measurements everywhere in the building (e.g. inside every room of the building). The calibration has to be done at least once in the beginning before the system can be used for positioning. Then the location of the user is calculated using a Kalman filter approach which is followed by a postprocessing step including sliding window averaging. Multiple mobile devices can be simultaneously tracked who have access to at least one access point.

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 (Pahlavan et al. 2002, Kong et al. 2004). With results of propagation measurement in a typical modern office building, it has been shown that the UWB signal does not suffer multipath fading (Win and Scholtz 1998), which is desirable for accurate ToA or TDoA estimation in indoor areas. Kong et al. (2004) achieved positioning accuracies in the range of 0·2 to 1 m at a 67% reliability level for indoor position determination using up to 8 base stations installed in a building.

RFID is employed in the consumer goods industry for the contactless transmission of information for product identification. Uninterrupted traceability of the merchandize within the supply chain, optimization of order management as well as enhanced product availability are but a few advantages of this new technology (Metro Group 2004). In future, RFID will replace the barcode for product identification. RFID consist of three components, i.e., tags (computer chips) which are in fact n-bit transponders, and readers with antennas. The reader is able to read the stored information of the tag in close proximity where the range is usually up to 6 m in the case of tags with batteries. For the underlying technology the reader is referred to e.g. Finkenzeller (2002). To employ RFID for positioning, one approach 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 the tag the RFID reader retrieves its ID and other information (e.g. the location). Such an approach is described by Chon et al. (2004) and they have shown that the tag can be read at vehicle speeds up to 150 km/h. Another possible application would be to install RFID tags at specific landmarks (or points of interest) and if the user passes by he can retrieve the tag information with its location. This would lead to the concept of active landmarks where the user of a navigation system is positioned using location information retrieved from the surrounding smart environment.

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. It can also be employed for location determination using active landmarks.

Apart from the location techniques described above, other methods have been developed for indoor location. Some of them are based on short-range or mid-range technologies using sensors such as transponders or beacons installed in the building. Also visual or optical tracking systems have been developed that employ specific markers that are installed around the building and used to detect the users current location (see e.g. Newman et al. 2004). 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, sport complex, 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 multistory building is another challenging task. For more accurate determination of the user's height an improvement is achieved employing a barometric pressure sensor or digital altimeter additionally (Retscher 2004).

Table 1 summarizes the possible positioning techniques as well as their observables and their corresponding accuracies. The table contains also specifications of relative sensors such as a digital compass, gyro, acceleration sensors for dead reckoning as well as inertial measurement systems (INS) that measure the heading, pitch, roll and the distance travelled of a user from a known start position. Future information about the dead reckoning sensors can be found in Retscher (2004) as well as Retscher and Thienelt (2004).

3. INTELLIGENT VEHICLE NAVIGATION.

Augmented reality (AR) technologies enable digitally stored information (virtual objects) to be overlaid on views of the real world. To increase safety in driving under poor visibility conditions, for example the road boundaries and other safety features (e.g. traffic signs) as well as other vehicles on the road can be overlaid an image of the real world. Thereby the AR systems rely on position and attitude parameters to register augmented objects with the real world environment. The accuracy with which these parameters can be determined, as well as the availability of the solution, can have a significant effect on the success of the AR system as a whole. To determine accurate and continuous outputs of position and attitude parameters (i.e., heading, pitch and roll), an array of three RTK GPS receivers, a fibre optic gyro and an odomter have

Table 1. Positioning technologies for navigation services with their corresponding observables and accuracies. Where *y, x, z* are 3-D coordinates of the current position, v_y, v_x, v_z are the 3-D velocities, a_x, a_y, a_z are the 3-D accelerations, a_{tan} is the tangential acceleration and a_{rad} is the radial acceleration in the ground plane *xy*, φ is the direction of motion (heading) in the ground plane *xy*, ψ is the pitch and θ is the roll. (Duffett-Smith and Craig 2004, Imst 2004, Kong et al. 2004, Chon et al. 2004, Crossbow 2004a, PointResearch 2004, Honeywell 2004, Crossbow 2004b, Vaisala 2004)

Positioning Method		Observations	Accuracy
GNSS	GPS	*y, x, z*	±6–10 m
	DGPS		±1–4 m
Velocity from GNSS		v_y, v_x	~ ±0·05 m^{-1}
		v_z	~ ±0·2 m^{-1}
Cellular Phone Positioning (GSM)	Cell ID	*y, x*	±150 m – 35 km
	Solo Matrix		±50–100 m
WLAN Positioning	IMST ipos	*y, x, z*	±1–3 m
UWB Positioning (TDoA)		*y, x, z*	±0·2–1 m
RFID Positioning (active landmarks)		*y, x, z*	±6 m
Bluetooth (active landmarks)		*y, x, z*	±10 m
Inertial Navigation Systems (INS)	Crossbow IMU700CA-200 Inertial Measurement Unit	a_x, a_y, a_z	< ±0·08 m s^{-2}
		φ, ψ, θ	< ±0·03 °/s
Dead Reckoning	PointResearch DRM-III Dead Reckoning Module	*y, x*	±20 – 50 m per 1 km
		z	±3 m
		φ	±1°
Heading	Honeywell Compass Module HMR 3000	φ	±0·5°
Acceleration	Crossbow Accelerometer CXTD02	a_{tan}, a_{rad}, a_z	> ±0·03 ms^{-2}
Barometer	Vaisala Pressure sensor PTB220A	*z*	±1–3 m

been employed (Kealy and Scott-Young 2004). The integration of the observations of these sensors in combination with map matching is performed using a Kalman filter approach which is referred to as "Intelligent *Vehicle* Navigation" (IVN).

The IVN algorithm developed is modelled on the simple rules of navigation that humans use on a day-to-day basis, and in doing so incorporates both geometric and topological map matching techniques. This algorithm has several advantages that are:

- It consists of a simple, yet effective set of four rules (closest road, bearing matching, access only and distance in direction).
- It relies on the short term precision of the navigation sensors (in particular DR when GPS is unavailable).
- It no longer assumes that the vehicle is on the road centreline, but instead it is 'following' the road network.

The closest road rule of IVN makes the assumption that the vehicle is travelling along a road (which is typically the case). This constraint can be included in the location solution, thus improving the accuracy of the computed position of the vehicle. This algorithm is most effective when the nearest road is in fact the road being travelled. However, when approaching intersections or when two roads are close to each other, the nearest road may not be the road being travelled. In such cases, constraining the solution to fall on the nearest road actually downgrades the calculated

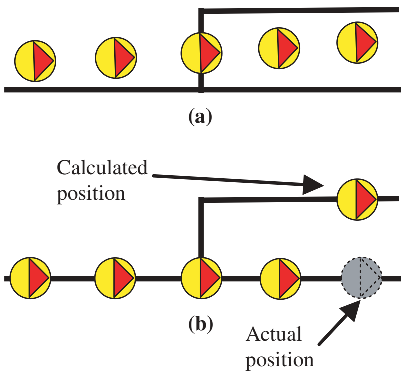

Figure 1. Correcting to the nearest road taking road bearing into account: (a) Navigation without correction (b) Navigation with correction (after Kealy et al. 2004)

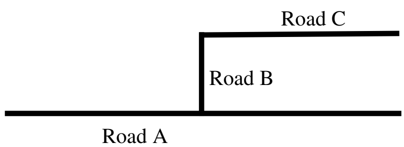

Figure 2. Road layout scenario (after Kealy et al. 2004)

position. To avoid such errors, the bearing matching rule is required. This rule requires that the nearest road to which the vehicle's position is corrected must have a bearing similar to the measured direction of travel. This corrects the problem previously described. The threshold of similarity between the vehicle's bearing and the bearing of the surrounding roads may be adjusted to suit the accuracy of the navigation sensors. However, the larger the threshold, the more likely it becomes that roads will be incorrectly matched as having the same bearing as that of the vehicle. Figure 1(b) shows a case where application of the closest road and bearing matching rules incorrectly position the vehicle. The access only rule is designed to identify and prevent this error from occurring. Take, for example, a vehicle travelling along road A in the road layout diagram shown in Figure 2. Assuming the only route to road C is via road B, logic dictates that for the vehicle to be travelling along road C it must previously have travelled along road B. By logging previously travelled roads, the navigation system can prevent the vehicle from being located on a road that it could not possibly be on. The fourth rule, i.e., the distance in direction rule, reduces the accumulation of distance error by calculating the distance travelled by the vehicle in the direction of the road rather than the direction measured by the heading sensor. This is particularly important when heading sensors of low accuracy are employed. For example, if a vehicle travels 1000 metres along a road of bearing 60 degrees while measuring the road to have a bearing of 65 degrees (i.e. 5 degrees in error), an error in distance of 4 metres will occur (Figure 3). Although this may seem insignificant, over several kilometres, or with lower accuracy navigation instruments, larger errors can accumulate. This error is avoided by calculating the distance travelled independently from the bearing of the vehicle and then applying this distance in the direction of the road being travelled.

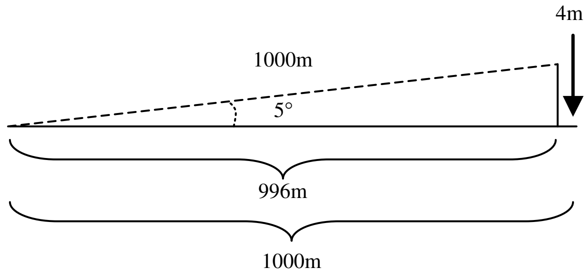

Figure 3. Distance error propagated from bearing measurement error (after Kealy et al. 2004).

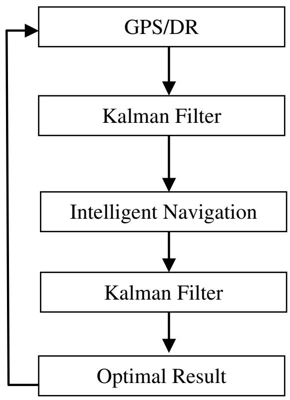

Figure 4. Kalman filter process with Intelligent Navigation (after Scott-Young 2004).

Incorporating IVN into the Kalman filter requires the development of observation equations from the IVN rules. The IVN observation equations are derived from the IVN estimate of the vehicle's 'corrected' position (which lies on a road segment) and an estimate of the vehicle's heading (i.e., the heading of the road segment at the IVN 'corrected' position). This procedure also allows for additional parameters to be estimated by the filter such as the offset from the centreline which is described by the Euclidean distance of the vehicle from the centreline. The process for including IVN information and the updated parameters for the state of the Kalamn filter is shown in the block diagram of Figure 4. Using data from GPS and DR sensors, the position and attitude of the vehicle are estimated. This information provides input for the IVN algorithms. The results from IVN are then combined with the GPS/DR measurements and filtered to provide an optimal solution using all available information. There is only one Kalman filter that has to be run twice where the first run provides the input for the IVN algorithms and secund run computes the optimal state of the mobile platform using all available measurements (i.e., GPS, DR and IVN). Further details about the algorithm can be found in Scott-Young (2004) as well as Kealy and Scott-Young (2004).

For the evaluation of the developed integration algorithm an AR prototype, i.e., ***i*ARM** (**I**ntelligent **A**ugmented **R**eality **M**apper), was constructed. Apart from the navigation sensors described previously, the ***i*ARM** consists of a digital video camera and a database containing 3-D objects used for augmentation. The system was

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installed on a typical land mobile vehicle. Figure 5a shows the augmented road boundaries on the real world image captured by the digital video camera. The results presented in the figure are typical of the visual registration accuracy of augmented data and the real world images. Figure 5b shows simulated poor visibility conditions. Despite these conditions the Intelligent Navigation Aid is able to highlight the road boundaries, clearly marking the edges of the road. If other vehicles are also positioned and their current location is transmitted to the system, then they can also be augmented to the digital image and the driver can 'see' them despite the poor visibility conditions.

4. PEDESTRIAN NAVIGATION SERVICES. A reliable pedestrian navigation service requires the determination of the current user's position using different sensors that are integrated into the system design. In the work package "Integrated positioning" of the research project NAVIO (Pedestrian **Nav**igation Systems in Combined **I**ndoor/**O**utdoor Environements) the following challenging tasks are addressed (Retscher and Thienelt, 2004):

- The capability to track the movements of a pedestrian in real-time using different suitable location sensors and to obtain an optimal estimate of the current user's position.
- The possibility to locate the user in 3 dimensions with high precision (that includes to be able to determine the correct floor of the user in a multi-storey building).
- The capability to achieve a seamless transition for continuous positioning determination between indoor and outdoor areas.

Thereby a navigation support must be able to provide location, orientation and movement of the user as well as related geographic information matching well with the real world situation experienced by pedestrians (Gartner et al. 2004a and b). The useable sensors and location techniques are summarized in Table 1. A Kalman filter approach is particular suited for the integration and sensor fusion in real-time. For further information on the employed multi-sensor fusion model the reader is referred to Retscher and Mok (2004) and Retscher (2005).

Practical tests in the NAVIO project are carried out for the guidance of visitors of the Vienna University of Technology to certain offices in different buildings or to certain persons. Thereby we assume that the visitor employs a pedestrian navigation system using different sensors that perform an integrated positioning. Start points are nearby public transport stops, e.g. underground station Karlsplatz in the centre of Vienna or railway station Südbahnhof near our university. In the following, first test measurements with the Dead Reckoning Module DRM III from PointResearch (2004) are presented. Figure 6 shows the dead reckoning observations as well as the GPS measurements along a 475 m long track in the park of Schönbrunn Palace in Vienna. In the dead reckoning module, measurements of accelerometers are employed to count the steps of the walking pedestrian and the distance travelled is obtained using a predefined value for the stride length. Using GPS observations the stride length can be calibrated. Furthermore a compass and a gyro are employed for measurement of the heading or direction of motion. The dead reckoning observations shown in Figure 6 have been obtained without using the GPS calibration. They reach

(a) (b)

Figure 5. Augmented images using the *i*ARM (Intelligent Augmented Reality Mapper) (after Scott-Young 2004).

deviations in the range of 7 m over a distance of 150 m and 20 m over 200 m from the given track. The GPS measurements have a maximum deviation of 7 m. Figure 6 shows also the resulting trajectory from the internal Kalman filter of the DRM III

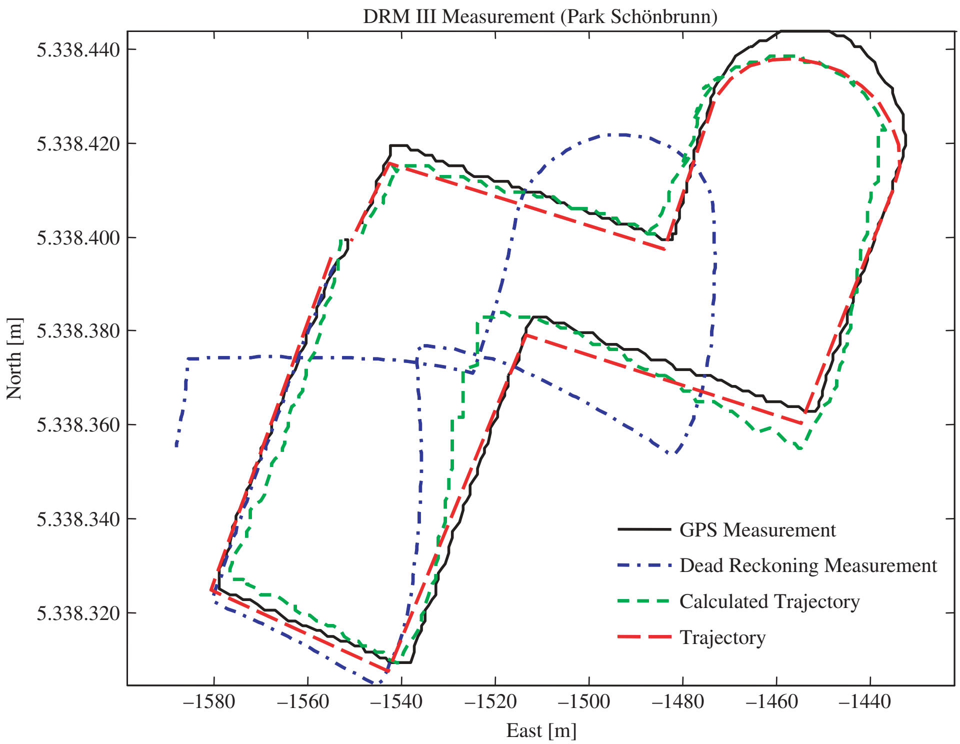

Figure 6. Test measurements with the Dead Reckoning Module DRM III in the park of Schönbrunn Palace in Vienna.

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module calculated from a combination of GPS and DR observations. It can be seen that the large drift rate of the DR observations can be reduced. Using the DR observations, GPS outages (i.e., when GPS is unavailable) up to 150 to 200 m can be bridged with a reasonable positioning accuracy. For longer GPS outages, however, other location technologies have to be employed providing an absolute position estimate or IVN rules have to be integrated within the Kalman filter to correct for the DR drift.

5. CONCLUSIONS AND FUTURE WORK.

Newly developed ubiquitous location technologies can be integrated in modern advanced navigation systems to augment common satellite positioning and dead reckoning. Due to their integration the performance, usability as well as reliability and integrity of the navigation service can be significantly increased. Nowadays also new low cost sensors (e.g. MEMS Inertial Measurement Units) can be employed for dead reckoning. Their performance was investigated in two different case studies. The aim of the first case study was to investigate the performance of an integrated position and attitude determination system to support AR applications in outdoor unprepared environments. Therefore multiple sensors and data sources were integrated in combination with map matching within a Kalman filter. Due to the integration of Intelligent Vehicle Navigation (IVN) rules into the filter a significant improvement to position and attitude determination during GPS outages could be achieved. In the case study the visualization of road boundaries and surrounding vehicles under poor visibility conditions for land vehicle navigation using an AR prototype was investigated. This has direct impact on safety aspects of driving. The second case study analyzed the use of multiple sensors and location techniques for pedestrian navigation services where the integration of the sensors is performed using a multi-sensor fusion model based on an adapted Kalman filter approach. First test measurement results using a dead reckoning module incorporating GPS are presented. A further refinement of the approach can be achieved by the integration of other ubiquitous location technologies (e.g. for indoor positioning) into the navigation service and the use of IVN rules based on map matching.

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