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Integration of RFID, GNSS and DR for Ubiquitous Positioning in Pedestrian Navigation

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Abstract. Location determination of pedestrians in urban and indoor environment can be very challenging if GNSS signals are blocked and only pseudorange measurements to less than four statellites are avialable. Therefore a combination with other wireless technologies for absolute position determination and dead reckoning (DR) for relative positioning has to be performed. Radio Frequency Identification (RFID) is an emerging technology that can be employed for location determination of a mobile user in indoor and urban environment. RFID transponders (or tags) can be placed at known location (so-called active landmarks) in the environment and the user who has to be positioned can carry a RFID transceiver (or reader). Then the location of the user can be obtained using cell-based positioning or with trilateration if ranges to several tags are deduced. In this paper the use of active RFID in combination with satellite positioning and DR is investigated. For that purpose the integration with GNSS and other wireless technologies is discussed and the deduction of ranges to RFID tags is investigated. Test results show that the ranges to RFID tags can be deduced from signal strength observations to tags in the surrounding environment. Two different models that describe either a logarithmic or linear relationship between the measured signal strength and the distance to the tag are analyzed. In addition, if pseudorange observations to GNSS satellites can be measured then they can also be used with ranges to RFID tags to obtain the position fx. The absolute position can then be used to update the drift rates of the DR sensors which are used for continuous position determination. Different scenarios for the correction of the DR drift are described in the paper. The presented research is conducted in a new research project at the Vienna University of Technology.

Keywords: Integrated positioning, Active RFID, GNSS, Dead Reckonig (DR), Minimum Range Error Algorithm (MRERA)

1 Introduction

In a new research project called “Ubiquitous Cartography for Pedestrian Navigation (UCPNAVI)” at the Vienna University of Technolgy we are currently exploring the capabilities of providing location based information and navigation via an ubiquitous environment to enhance route guiding in smart environments. The research 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 central server-based solutions. Different techniques and sensors are tested and a knowledge-based multi-sensor fusion model is applied (see Retscher, 2005; Thienelt et al., 2007) to enhance location determination in smart environments.

Especially in complex buildings, visitors often need guidance and support. Studies showed that people tend to lose orientation a lot easier within buildings than outdoors, especially if not moving along windows (see e.g. Hohenschuh 2004, Radoczky 2003). Additionally to navigation support it could be beneficial to supply the user with information that is adapted to the current task, e.g. 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 an 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. 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.

In a first step, the use of RFID (Radio Frequency Identification) for ubiquitous positioning is investigated in the project. For location determination RFID tags can be placed at active landmarks or at 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. From measured signal power levels the corresponding range to the tag’s location can be deduced. If ranges to at least three RFID tags are available then the position fix can be obtained using trilateration.

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. The absolute position determination is usually performed with satellite positioning (GNSS). RFID positioning can provide this position updates in smart environments where satellite positioning is not available.

In this paper the positioning of a mobile user in urban environment based on RFID in combination with GNSS and Dead Reckoning (DR) is investigated.

2 Use of Active RFID in Positioning

Radio Frequency Identification, or RFID for short, is an automatic identification method. An RFID tag is a transponder that can be attached to or incorporated into a product, animal, or person for the purpose of identification using radiowaves. Other system components include a reader (i.e., a transceiver) with antenna. The reader is able to read the stored information of the tag in close proximity. RFID tags contain antennas to enable them to receive and respond to radio-frequency queries from an RFID transceiver. Passive, active and semi-passive tags can be distinguished. 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 a few mm up to several meters. 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 meters, and a battery life of up to several years. Further information about the underlying technology can be found in Finkenzeller (2002).

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 detect an object when passing by. For that purpose an RFID tag is attached to or incoporated in the object. This concept is employed for example in theft protection of goods in shops and in warehouse management and logistics. A second approach for using RFID in positioning would be to install RFID tags at known locations (e.g. at active landmarks) especially in areas without GPS visibility (e.g. in tunnels, under bridges, indoor environments, etc.) and have a reader and antenna installed in the mobile device carried by the user. When the user passes by the tag the RFID reader retrieves its ID and other information (e.g. the location).

Positioning can be performed using Cell of Origin (CoO). The maximum range of the RFID tag defines a cell of circular shape 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 accuracy of position determination is defined by the cell size. Using active RFID tags the positioning accuracy therefore ranges between a few meters up to tens of meters. Using a configuration of the achievable range of the RFID tags, however, the signal strength can be set in steps of 2 dBm between -40 dBm and +60 dBm which corresponds in a diameter of the cell ranging from 2 up to 50 m in areas with free visibilty. The optimal size of the cell can then be set at 4 m.

Higher positioning accuracies can be obtained using trilateration if the ranges to several tags are determined and are used for intersection. For 3-D positioning range measurements to at least three tags are necessary. The ranges from the antenna of the reader to the antenna of the tag is deduced from the conversion of signal power levels into distances. Strategies for the conversion of the signal strength measurements into distances for urban outdoor areas will be discussed in the following section.

3 Signal strength to distance conversion for RFID range deduction

To transform the measured signal strength from the RFID tag into a range between the tag and the reader a conversion model has to be employed. This conversion can be performed using a radio wave propagation model. Such a model is an empirical mathematical formulation for the characterization of radio wave propagation as a function of frequency, distance and other conditions. Such models typically predict the path loss along a link or the effective coverage area of a transmitter. For outdoor urban environments a suitable model is the Okumura-Hata Model.

The Okumura-Hata model is the most widely used model in radio frequency propagation for predicting the behaviour of cellular transmissions in built up areas. This model incorporates the graphical information from the Okumura model and develops it further to realize the effects of diffraction, reflection and scattering caused by city structures. This model also has two more varieties for transmission in suburban areas and open areas. The Hata Model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications (Wikipedia, 2007; Ranvier, 2004).

The Okumura-Hata model will be used for modelling of the propagation of the RFID signals outside buildings. This model assumes that the received signal power decreases logarithmically with the distance from the transponder. It can be mathematically described as:

$$s_T = A + B \cdot \log_{10} d + C \tag{1}$$

where

s_T is the total signal strength in [dB],

d *is* the distance between the RFID tag and the RFID reader in [km] and

A, *B*, and *C* are coefficients that depend on the frequency and antenna heights.

The coefficients *A*, *B*, and *C* can be described as

$$A = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) \tag{2}$$

$$B = 44.9 - 6.55\log_{10}(h_t) \tag{3}$$

where

f_c is the carrier frequency in [MHz],

h_t is the RFID tag height above local terrain height in [m],

h_r is the RFID reader antenna height above local terrain height in [m] and

$a(h_r)$ is a correction factor for the antenna height of the RFID tag.

The factors $a(h_r)$ and *C* depend on the surroundings as follows:

- **Urban areas:**

- *Small and medium-size cities*:

$$a(h_r) = (1.1\log_{10}(f_c) - 0.7)\cdot h_r - (1.56\log_{10}(f_c) - 0.8)$$
$$C = 0 \tag{4}$$

- *Metropolitan areas*:

$$a(h_r) = \begin{cases} 8.29[\log_{10}(1.54h_r)]^2 - 1.1 & \text{if } 150 \le f_c \le 200 \text{ MHz} \\ 3.2[\log_{10}(11.75h_r)]^2 - 4.97 & \text{if } 200 < f_c \le 1500 \text{ MHz} \end{cases}$$
$$C = 0 \tag{5}$$

- **Suburban areas:**

$$C = -2[\log(f_c/28)]^2 - 5.4 \tag{6}$$

- **Open areas:**

$$C = -4.78[\log(f_c)]^2 - 18.33\log(f_c) - 40.94 \tag{7}$$

In the case of RFID the carrier frequency of the employed system is f_c = 865.35 Mhz. The RFID tags are installed along the road at the same height, and the RFID reader will be carried by the user at a constant antenna height. Thus, the parameters carrier frequency f_c, RFID reader antenna height above local terrain height h_r and RFID tag height above local terrain height h_t can be treated as constant. For this reason, the equations above can be simplified by using the parameters total signal strength s_T and distance *d* between the RFID tag and the RFID reader. Also the unit for the distance can be changed from [km] to [m] and for the signal strength from [dB] to

[dBm]. The relationship between the signal strength and the distance can then be expressed as:

$$s_T = a_0 + a_1 \cdot \log_{10} d \quad (8)$$

where

a_0 and a_1 are coefficients found during calibration using measurements on a known baseline.

The distance d between the RFID tag and the RFID reader can then be determined as follows:

$$d = 10^{\frac{s_T - a_0}{a_1}} = 10^{[b_0 + b_1 \cdot s_T]} \quad (9)$$

with the coefficients $b_0 = -\frac{a_0}{a_1}$ and $b_1 = \frac{1}{a_1}$.

For further improvement of the accuracy of the approximation, the exponent in equation (9) can be extended by a polynomial function of order p as described in the following equation:

$$d = 10^{[b_0 + b_1 \cdot s_T + b_2 \cdot s_T^2 + \ldots + b_p \cdot s_T^p]} \quad (10)$$

where

p is the order of the polynomial function,

$b_0, b_1, b_2, \ldots, b_p$ are the coefficients of the polynomial function determined from a calibration.

The conversion has been tested in suburban outdoor environment with obstructions caused by three- to four-storey buildings. Fig. 1 shows the relationship between the measured signal strength and the known distance along a baseline. The signal strength has been measured along the baseline from 1 m up to a distance of 12 m from the RFID tag with an 1 m interval at four different orientations of the antenna of the RFID reader. Fig. 1 shows the measurements to one tag in direction 1. For the conversion of the signal strength to a distance the logarithmic model described in equation (10) has been employed. A good approximation is achieved if an order of $p = 8$ is chosen.

In Fig. 2 the residuals between the logarithmic model approximation and the measured signal strength values are shown. As can be seen from this figure, the standard deviation for the conversion of the signal strength into a distance is only ± 0.52 m using this model with a mean value of 0.03 m.

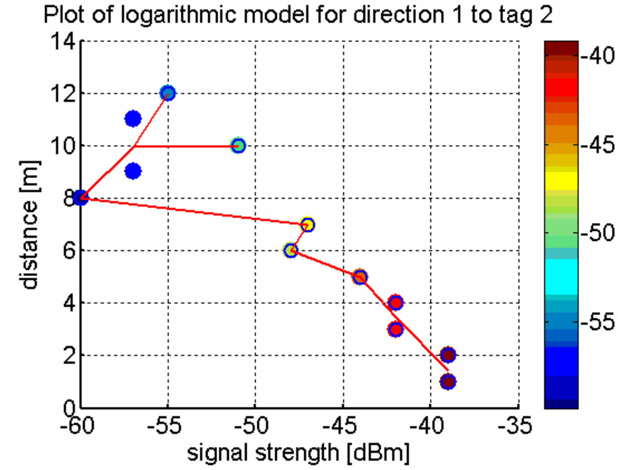

Fig. 1. Relationship between the measured signal strength and the distance along a baseline described by a logarithmic model of order $p = 8$

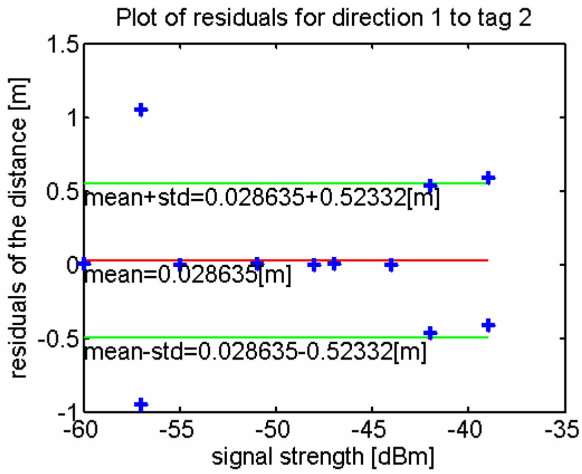

Fig. 2. Residuals between the logarithmic model and the measured signal strength along a baseline

Apart from using a logarithmic relationship between the signal strength and the distance also the use of a linear regression was investigated. For that purpose a polynomial function of the order p in the form of

$$d = a_0 + a_1 \cdot s + a_2 \cdot s^2 + \ldots + a_p \cdot s^p \quad (11)$$

where

d is the distance to the RFID tag in [m],

s is the measured signal strength in [dBm] and

a_p are the unknown coefficients of the polynomial function,

can be used to describe the relationship between the signal strength and the distance. The unknown coefficients a_p can be computed using a least squares fit if the signal strength s is measured along a baseline at n

known regular distances. Then there are n equations with p+1 unknowns (where n must be > p+1).

The possible order p of the polynomial function depends on the number of available signal strength observations n and the desired level of approximation. Fig. 3 shows a linear regression model of order p=8 for the signal strength to distance conversion and Fig. 4 the corresponding residuals between the polynomial model approximation and the measured signal strength values. By comparing Fig. 1 with 3 can be seen that both models achieve a nearly similar result for the signal strength to distance conversion. Using the polynomial model the resulting mean value of the residuals is, however, only $7.3*10^{-7}$ m and the standard deviation for the conversion of the signal strength into a distance is a bit smaller than that of the logarithmic model (i.e., only ± 0.52 m) (see Fig. 4). Due to the slighty better results it can therefore be recommended to employ a polynomial model of high order for the distance conversion of the ranges between the RFID tag and the reader. A major advantage of the polynomial conversion model is also that it is easier to handle than the logarithmic approach.

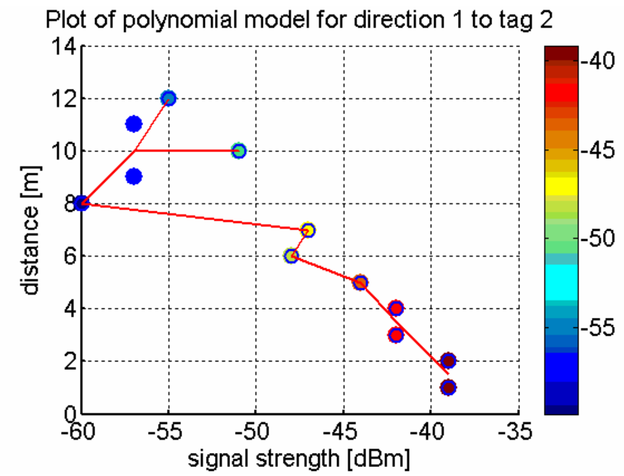

Fig. 3. Relationship between the measured signal strength and the distance along a baseline described by a polynomial model of order p = 8

If several RFID tags are located in the surrounding environment the current position of the RFID reader can be obtained using trilateration. Then the deduced distances to at least three RFID tags are needed to calculate a position fix with intersection. If more than three distances are available, the position fix can be calculated using a least squares adjustment.

The deduced ranges to RFID tags can not only be used to obtain the position fix in indoor and urban environments using trilateration, but also to supplement the GNSS positioning in outdoor urban environments. Then the available pseudorange observations to satellites should be used together with the range observations to RFID tags to obtain the position fix. In the following sections, a GNSS algorithm for position determination in urban environments with pseudorange measurements to less than four satellites is described and then the integration with RFID and other wireless technolgies is discussed.

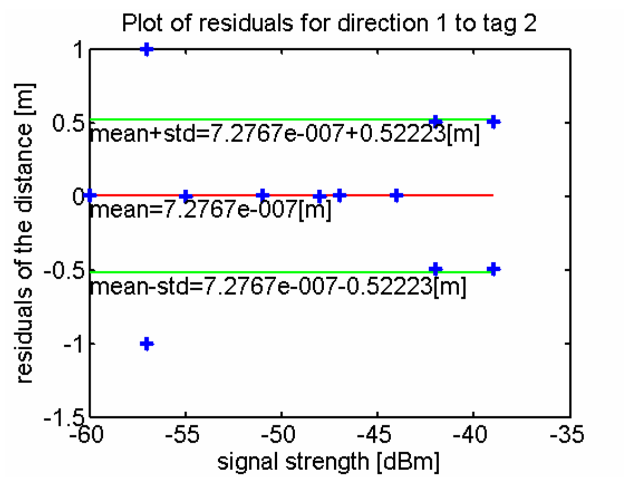

Fig. 4. Residuals between the polynomial model and the measured signal strength along a baseline

4 Operation principle of the minimum range error algoritm (MRERA) for GNSS positioning

GNSS positioning in urban environments can be significantly affected by signal blockage due to obstructions and therefore it frequently happens that less than the minimum required number of four satellites are available to obtain a 3-D position fix. Mok and Lau (2001) proposed an algorithm that is able to estimate positions even with three or less satellites, i.e., the "Minimum Range Error Algorithm" (MRERA). MRERA was originally developed for vehicle tracking to locate vehicles in dense high-rise environments without the use of DR sensors. But it can also be employed for general geolocation and mobile positioning applications. The basic principle of operation of the MRERA is illustrated in Fig. 5.

Consider that a series of "road points" with known coordinates in WGS84 are stored in a road network database. When travelling along a section of road and continuously receiving GPS signals from at least one satellite, the pseudorange observations and the geometric range computed from the known satellite and road point positiones can be obtained. After correction of the pseudorange observations for ionospheric, tropospheric, multipath and receiver clock errors, the difference between the geometric range and the measured GPS pseudorange can be calculated. This range difference will vary depending on the distance of the GPS receiver from the road point. In other words, if the GPS user is travelling towards a particular road point, the range difference will decrease. The difference will reach its minimum value when the user is nearest to the road point, then increasing when the user is moving away from the road point. This phenomenon is illustrated in Fig. 6.

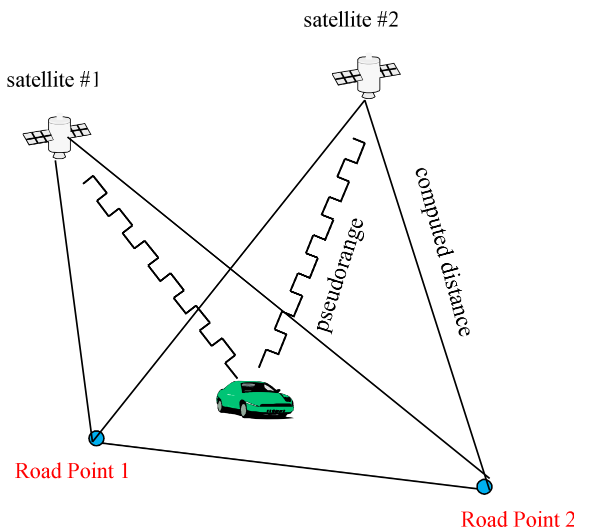

Fig. 5. Principle of the MRERA approach showing a vehicle's position between road points 1 and 2 (after Mok et al., 2007)

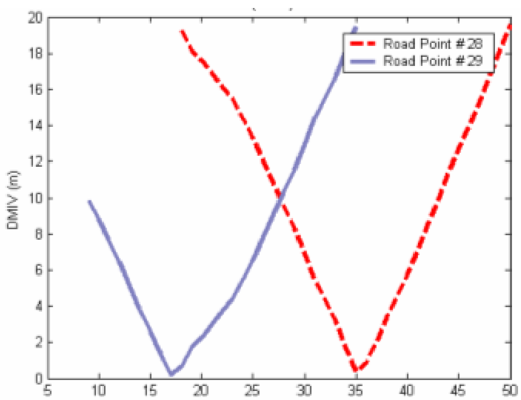

Fig. 6. The minimum of the difference between the measured GPS pseudorange and the geometrical range to one satellite arises when the GPS receiver is nearest to the road point's location (after Mok et al., 2007)

The geometric range $\rho_i^j(t)$ from the satellite j to the road point i at epoch t can be determined using the following equation:

$$\rho_i^j(t) = \sqrt{(X^j(t) - X_i)^2 + (Y^j(t) - Y_i)^2 + (Z^j(t) - Z_i)^2} \qquad (12)$$

where

$X^j(t), Y^j(t), Z^j(t)$ are the WGS84 coordinates of a satellite j (with $j = 1, 2, 3, \ldots, M$) at time t and

X_i, Y_i, Z_i are the WGS84 coordinates of a road point i (with $i = 1, 2, 3, \ldots, N$).

The pseudorange $R_r^j(t)$ from satellite j to receiver r observed at epoch t can be expressed as

$$R_r^j(t) = \rho_r^j(t) + c(\delta t^j(t) - \delta t_r(t)) + \varepsilon \qquad (13)$$

where

$\rho_r^j(t)$ is the geometric range from satellite j to the GPS receiver r at epoch t,

c is the speed of light,

$\delta t^j(t)$ is the satellite clock bias at epoch t and

$\delta t_r(t)$ is the GPS receiver clock bias at epoch t,

ε are other errors such as ionospheric and tropospheric biases and multipath errors.

After applying corrections to the measured pseudorange $R_r^j(t)$ the range difference between the geometric range to the road point $\rho_i^j(t)$ and the measured GPS pseudorange $R_r^j(t)$ can be calculated. The minimum of this range difference is obtained when the GPS receiver r is nearest to the road point i. Then the MRERA Indicator Value (*MIV*) at the road point i given as

$$MIV_i(t) = \sum_{j=1}^{M} \left| \rho_i^j(t) - R_r^j(t) \right| \qquad (14)$$

reaches its minimum value for every tracked satellite j (with $j = 1, 2, 3, \ldots, M$). In theory, the determination of *MIV* is possible with all available satellites. In confined areas with obstructions, however, the number of satellites *M* would normally be less than three. If more than three satellites are available, *MIV* can also be used to verify the receiver location under weak satellite-receiver geometry (i.e., large DOP value). For further information about the basic principle of MRERA the interested reader is referred to the work of Mok and Lau (2001) or Mok and Xia (2006).

Further development was concentrated on the supplementation of the standalone GPS mode with other wireless technologies. An integration of range measurements to WiFi and UWB base stations into MRERA was first proposed by Mok and Xia (2005). In simulations it could be seen that an integration of GPS pseudoranges and ranges to ground transmitters can be performed meaningful under the MRERA. Apart from WiFi and UWB also the use of ranges to active landmarks equipped with active RFID has been proposed (see Mok et al., 2007) and will be described in the following section.

5 Integration of RFID and other ground based wireless technologies with GNSS using enhanced MRERA

Consider the situation that pseudorange observations to only one or two GPS satellites are possible (which would not give a position fix in standalone GPS mode) and also ranges to ground based transponders (e.g. an active landmark equipped with a RFID tag) or transmitters (e.g. an WiFi access point or an UWB base station) at a particular location can be obtained. Then these observations should be used together to determine an absolute position fix. The location of the active landmark serves then in the MRERA algorithm as the road point with known coordinates (compare Fig. 5) and the respective range to the landmark can be used together with the GPS pseudoranges for obtaining the position fix.

The obtained ranges to the active landmark shall be integrated with other observations from radio transmitters, e.g. pseudorange observations to GNSS satellites, if positioning is performed in urban environment. Then the integrated observation and positioning model does not only include the observation equations for the satellite positioning systems (i.e., GPS, GLONASS, future Galilieo), but also the range observations from ground based transmitters (i.e., the WiFi access points or UWB base stations and RFID landmarks). This leads to the following functional model:

$$\begin{bmatrix} R_r^1(t) \\ R_r^2(t) \\ \vdots \\ R_r^j(t) \\ R_r^{G1}(t) \\ R_r^{G2}(t) \\ \vdots \\ R_r^{Gk}(t) \end{bmatrix} = \begin{bmatrix} \rho_{r0}^1(t) \\ \rho_{r0}^2(t) \\ \vdots \\ \rho_{r0}^j(t) \\ \rho_{r0}^{G1}(t) \\ \rho_{r0}^{G2}(t) \\ \vdots \\ \rho_{r0}^{Gk}(t) \end{bmatrix} - \begin{bmatrix} l_r^1(t) & m_r^1(t) & n_r^1(t) & -1 \\ l_r^2(t) & m_r^2(t) & n_r^2(t) & -1 \\ \vdots & \vdots & \vdots & \vdots \\ l_r^j(t) & m_r^j(t) & n_r^j(t) & -1 \\ l_r^{G1}(t) & m_r^{G1}(t) & n_r^{G1}(t) & 0 \\ l_r^{G2}(t) & m_r^{G2}(t) & n_r^{G2}(t) & 0 \\ \vdots & \vdots & \vdots & \vdots \\ l_r^{Gk}(t) & m_r^{Gk}(t) & n_r^{Gk}(t) & 0 \end{bmatrix} \begin{bmatrix} \delta X_r \\ \delta Y_r \\ \delta Z_r \\ \delta t_r \end{bmatrix} \tag{15}$$

where

$R_r^j(t)$ are the pseudorange observations from satellite j to receiver r at epoch t,

$R_r^{Gk}(t)$ are the equivalent range observations from ground based transmitters (or active landmarks) k to the current user's location r at epoch t,

$\rho_{r0}^j(t)$ is the range vector from satellite j to GPS receiver r in the WGS84 coordinate frame at epoch t,

$\rho_{r0}^{Gk}(t)$ is the range vector from the base station of the ground transmitter network (or the active landmark) k to the mobile station r in the corresponding coordinate frame at epoch t,

$l_r^j(t)$, $m_r^j(t)$ and $n_r^j(t)$ are the direction cosines from the tracked satellite j to the observation point r at epoch t,

$l_r^{Gk}(t)$, $m_r^{Gk}(t)$ and $n_r^{Gk}(t)$ are the direction cosines from the ground transmitter k to the mobile station r at epoch t,

δX_r, δY_r and δZ_r are the coordinate differences for point r and

δt_r is the receiver clock bias of the GPS receiver.

Thereby in equation (15) it is assumed that the range vector from the base station of the ground transmitter network $\rho_{r0}^{Gk}(t)$ is given in the GNSS reference frame, i.e., the WGS84 in the case of GPS. The unknown coordinate differences δX_r, δY_r and δZ_r are obtained from the least squares adjustment described by the well-known form:

$$\delta X = -(A^T PA)^{-1} A^T PL \tag{16}$$

The observation weight matrix P in equation (16) contains two parts that corresponds to the GNSS psudoranges and range observations from ground transmitter stations or active landmarks. If σ_{GNSS} and σ_G are used to indicate the standard deviations of the unit weight for satellite pseudoranges and ground transmitter network ranges respectively, and different observation types are assumed to be uncorrelated, it has the form:

$$P = \begin{bmatrix} 1/\sigma_{GNSS}^2 & & & & & \\ & 1/\sigma_{GNSS}^2 & & & & \\ & & 1/\sigma_{GNSS}^2 & & & \\ & & & 1/\sigma_G^2 & & \\ & & & & 1/\sigma_G^2 & \\ & & & & & 1/\sigma_G^2 \end{bmatrix} \tag{17}$$

The standard deviation σ_{GNSS} can be set according to the GNSS positioning mode and the standard deviation σ_G according to the different kind of the ground transmitter network.

Using the model described above ranges to UWB and WiFi transmitters or RFID transponders can be integrated with GNSS pseudoranges to obtain the most optimal location result. The varied forms of observations can be pseudoranges, time delays, time delay differences or signal strengths. They can all be converted to the geometrical distance after some transformation. For instance, the distance can be estimated from the signal strength which is based on the relation of the signal propagation loss on the traveling path. All observations from UWB, GNSS, WiFi or RFID can be used in a tightly coupled processing model in form of a Kalman filter based on the observation domain, from which both position and velocities are derived (Mok and Xia, 2005).

An important consideration for hybrid positioning is the coexistence of different kinds of observations such as data from GNSS, UWB, WiFi, RFID or other mobile networks. Each has its own quality feature that is described by its variance value of the unit weight. Therefore in data processing, system performance evaluation based on observation residuals will reflect system performance if the unit weight variance is unique. To objectively evaluate hybrid location performance, a Helmert variance estimation model was proposed to optimize the quality evaluation based on an iterative estimation of the unique variance of the unit weight. Further details can be found in the papers of Mok and Xia (2005) and Xia et al. (2006).

6 Integration with dead reckoning (DR)

Most navigation systems also employ dead reckoning (DR) sensors for the direct observation of the direction of motion (or heading) and the distance travelled from a known start position. In the project at least the following DR sensors are included: an attitude sensor (i.e., a digital compass) giving the heading in combination with an inertial tracking sensor (e.g. a low-cost MEMS-based Inertial Measurement Unit IMU) including a three-axis accelerometer also employed for travel distance measurements as well as a digital barometric pressure sensor for altitude determination.

The major disadvantage, however, of DR sensors is the accumulation of large drift rates after short time if no suitable update with an absolute position is available. Depending on the environment in which the user is currently moving an update of the DR derived positions can be achieved with absolute positions from the following location methods:

- GNSS positions in unobstructed outdoor environments,
- a combination of GNSS and RFID in outdoor urban environments where blockage of satellite signals occurs,
- positions determined by RFID trilateration in areas where no GNSS signals are available,
- primarily from RFID derived positions in indoor environment as pseudoranges to GPS satellites (if available) are usually less accurate,
- or a combination of RFID and other wireless technologies such as WiFi or UWB in the case of their availability.

For the integrated position determination an extended Kalman filter (EKF) approach can be employed. In a tightly coupled EKF the GPS pseudorange measurements and ranges to RFID tags can be integrated with compass heading, and INS-derived position and attitude information as well as barometric height.

Another strategy is to use self calibration routines for the DR sensors for areas where no absolute positions at all for the correction of the DR drifts are available. Grejner-Brzezinska et. al. (2007) proposed to calibrate the DR observations (step length and step frequency from the MEMS-based IMU as well as the heading from the digital compass and the altitude from the barometer) under GPS signal blockage using the knowledge of the human locomotion model when GPS is available. In other words, a training mode under GPS availability is used to calibrate the human dynamics model (step length and step frequency) as well as the digital compass and barometer with artificial neural networks (see e.g. Wang et al., 2006) and fuzzy logic (see e.g. Abdel-Hamid et al., 2006) and the calibrated observations are then used in the DR navigation if GPS is unavailable. Training data that feed the artificial neural network or a fuzzy logic based adaptive knowledge systems are collected for each operator separately, and functions, such as step frequency, rate of step frequency, terrain slope, operator's locomotion pattern (e.g., standing, walking, jogging, sprinting, climbing, etc.), as a function of sensor outputs are analyzed to form the fuzzy rules that are subsequently used in the actual DR navigation mode. This approach is very promising, but it is still in the development stage and further investigations are therefore required.

7 Conclusions and outlook

In this paper the use of active longrange RFID tags for positioning using signal power levels that are converted to distances as well as their integration with GNSS observations has been discussed. Ranges have been deduced from the measured signal power levels using a logarithmic and polynomial conversion model. In the test experiments it could be seen that for the conversion of the signal strength into a distance a polynomial model with an order of p=8 gives good results. The tests have been performed along a baseline in suburban outdoor environment for ranges of up to 12 m from the RFID tag. Further testing is required using longer distances from the tags in different environments.

The deduced ranges can be used to obtain a position fix with trilateration if ranges to several RFID tags are measured, on the one hand, or in combination with GNSS pseudorange observations in obstructed areas, on the other. The integration algorithm for pseudorange observations to GPS satellites and range measurements to ground based transmitters or transponders has been discussed in the paper. Practical testing of this approach will be performed in the near future and their results will be reported elsewhere.

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