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OVERVIEW OF CURRENT INDOOR POSITIONING SYSTEMS

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Abstract. Precise positioning in indoor environments faces different challenges than the outdoor ones. While indoor environments are limited in size to rooms and buildings, outdoor positioning capabilities require regional or even global coverage. Secondly, the difficulty of receipting satellite signals indoors has triggered the development of high sensitive and AGNSS receivers – with many issues remaining unsolved. Thirdly, the accuracy requirements are dissimilar between indoor and outdoor environments – typically there is a higher demand for relative accuracy indoors. This paper should be regarded as an overview of the current and near future positioning capabilities for indoor and outdoor environments. However, it does not lay claim to completeness. Focus is given on various novel position systems that achieve cm-level accuracy or better which is a requirement for most geodetic applications.

Keywords: indoor positioning, GNSS, wireless networks, novel positioning systems, future positioning scenarios.

1. Introduction

Today, total stations cover most geodetic applications for determining 3D real-time positions indoors. However, to access increased availability, various weaknesses remain inherent in total station systems such as the requirement of direct line-of-sight and manual setup of a relatively large sized and expensive instrument. This paper addresses these weaknesses and looks forward to alternative positioning methods that may enable a 'Millimeters Everywhere' scenario in the near future. Unfortunately, locations inside buildings, basements and tunnels remain harsh environments for precise positioning. Typical indoor environments contain multiple walls and a large number of obstacles that consist of various materials. As a result, current indoor positioning systems cannot satisfy the challenging demands for most indoor applications. This insufficiency may explain the diversity of current indoor position systems – see Fig. 1.

Some attempts exploit new sensors that measure inter-nodal ranges, signal strengths, acceleration or angles for localisation as well as research, leading to higher sensitivity algorithms for signal acquisition and tracking in harsh environments. There is also the trend of combined usage or integration of different sensor systems and data sources. The large number of available sensors has lead to a variety of localisation schemes such as triangulation, trilateration, hyperbolic localisation, data matching and many more.

The employed signal technologies include RF (radio frequency) technology, ultrasound, infrared, vision-based systems and magnetic fields. The RF signal-based technologies can be split into WLAN (2.4 GHz and 5 GHz band), Bluetooth (2.4 GHz band), Ultrawideband and RFID.

In general, most techniques and algorithms can be applied for both outdoors and indoors. This paper focuses on innovative positioning hardware and techniques that are currently or in the near future available to determine positions inside buildings or in the underground.

2. AGNSS & high sensitivity receivers

Radio signal attenuation from walls causes standard GNSS receivers to perform poorly in indoor environments. The weak signals from the satellites become nearly undetectable for the receivers. Depending on the electrical properties such as the dielectric coefficient of the building material, GNSS signals are attenuated indoors by 20–30 dB (a factor of 100–1000) compared to outdoors (Table 1). As a consequence, the attenuation in buildings is 5–15 dB for residential houses, 20–30 dB for office buildings and >30 dB for underground car parks and tunnels, see Table 2.

Table 1. Attenuation of various building materials for the L-Band (L1 = 1500 MHz), according to Stone (1997)

Material	[dB]	Factor [-]
Dry wall	1	0.8
Plywood	1–3	0.8–0.5
Glass	1–4	0.8–0.4
Painted glass	10	0.1
Wood	2–9	0.6–0.1
Iron mat	2–11	0.6–0.08
Roofing tiles / Bricks	5–31	0.3–0.001
Concrete	12–43	0.06–0.00005
Ferro-concrete	29–33	0.001–0.0005

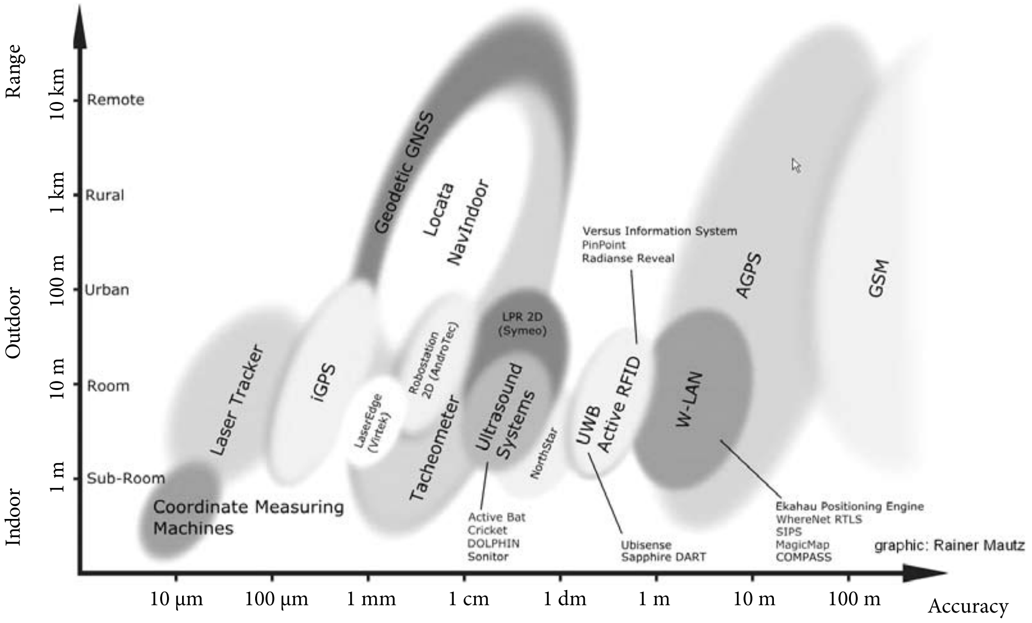

Fig. 1. Current positioning systems according to their accuracy and coverage area

Table 2. Signal strength in decibel watt (decibels relative to one watt) of GNSS satellites

Environment	[dBW]	Comment
Satellite	+ 14.3	signal strength delivered from satellite
Outdoors	−155	unaided fixes OK for standard receivers
Indoors	−176	decode limit for high sensitive receivers
Underground	−191	decode limit for aided, ultra-high sensitive receivers

The AGNSS or AGPS (Assisted GPS) addresses this problem. AGPS is successfully used for localisation of mobile phones. A data link via mobile phone provides information of the satellite Ephemeris, Almanac, differential corrections and other relevant information that is normally obtained from the GNSS satellites directly. As a consequence, the AGPS receiver can more easily lock on the satellites and obtain a fix position – assuming that some weak GNSS signals can be received.

In order to make use of the weak satellite signals indoors, the low signal to noise ratio is improved by integration over multiple intervals, which, on the other hand, requires longer acquisition times. Massive parallel correlators in the GNSS receivers are used to reduce the computing time and power of the receiver during the correlation process by a factor of 500 or more (Eisfeller *et al.* 2005). Furthermore, AGPS provides external frequency information that reduces the search interval for the GNSS satellites.

Eisfeller concludes that acquisition of GNSS signals in environments with signal attenuation of >25 dB (basements, concrete buildings) is not possible without AGPS. The AGPS accuracy indoors does currently allow room identification. In order to provide cm-level accuracy, the AGPS will need to be enhanced by DGPS methods. Currently, with the use of SBAS (Satellite Based Augmentation System) 10 m accuracies are typical for indoor environments (e.g. Opus III from eRide).

Lachapelle (2004) concludes that the currently achievable performance indoors can serve the emerging location-based services market. With better signal tracking, the use of new GPS and Galileo signals and various improvements within the next 10 years, a new level of indoor performance with GNSS will be reached.

3. Pseudolites using GNSS similar signals (LOcata)

The Locata technology consists of a network of terrestrially-based and time-synchronised pseudolite transceivers, as shown in Fig. 2, that transmit GNSS-like signals for single-point positioning using carrier-phase measurements. Barnes *et al.* (2003) achieved a real-time positioning standard deviation of 6 mm or 1 cm 93% of the time to a maximum of 100 m distance. In a kinematic test, 16 mm standard deviation with 82% values being less than ±20 mm. The authors conclude that their system can operate indoors and outside anywhere within sub-cm accuracy despite multipath errors. The Locata Technology Primer (2005)

Fig. 2. Locata antenna (Barnes *et al.* 2005)

Fig. 3. Leica Laser Tracker LTD 840 and Absolute Tracker AT901. Pictures from EMO Hannover and Magazine Archives

demonstrates a standard deviation of better than 5 mm indoors. Barnes *et al.* (2005) demonstrate the suitability of the Locata technology for machine tracking/guidance in factories or warehouses where GNSS satellite coverage is limited. Barnes *et al.* (2007) conclude that movements of less than 1 cm can be detected. Due to the signals being orders of magnitude stronger than GNSS, Locata signals can penetrate walls. However, the performance degrades to decimetre level accuracy inside buildings.

4. Laser tracker (Leica Geosystems, Faro, ATT)

Laser trackers as shown in Fig. 3 are usually portable instruments that combine angular and distance measurements using a laser interferometer or an absolute distometer to determine 3D coordinates. A typical maximum range is 15 m, expandable to 30 m or 70 m. Accuracies of 0.001" or 10 μm + 5 ppm (μm/m) can be reached. The principle is that a laser tracker sends a beam to a reflector sends it back to a rotating sensor – in order to determine the horizontal and vertical angles to the reflector. For dynamic tracking, the system can follow the target automatically via the survey beam.

5. Resection using infrared Laser (iGPS)

iGPS is a high-precision tracking system offered by Metris that allows monitoring of several sensors simultaneously. It has a range from 2 m to 80 m for indoor and outdoor applications. According to the manufacturer, an accuracy of ±0.1 mm for 3D positions can be reached. The principle is that 2 or more iGPS transmitters continuously send out infrared signals and rotating fan-shaped laser beams. According to Fig. 4, the first laser beam follows the second at a 90° angle. Both laser beams have an inclination of 30° from the vertical (one to the left, the other 2 the right). The vertical angle between transmitter and sensors is determined by the time interval between the 2 laser beams. The horizontal angle can be derived from the time interval between a third signal that is sent out every other rotation and the arrival of the laser beams. With receiving light signals form multiple transmitters simultaneously the own 3D position of a sensor is determined from multiple horizontal and vertical angles by spatial forward intersection. A more detailed description of the system can be found in Krautschneider (2006). He concludes that the dynamic mode allows real-time applications such as machine control and monitoring. Fig. 5 shows some system components.

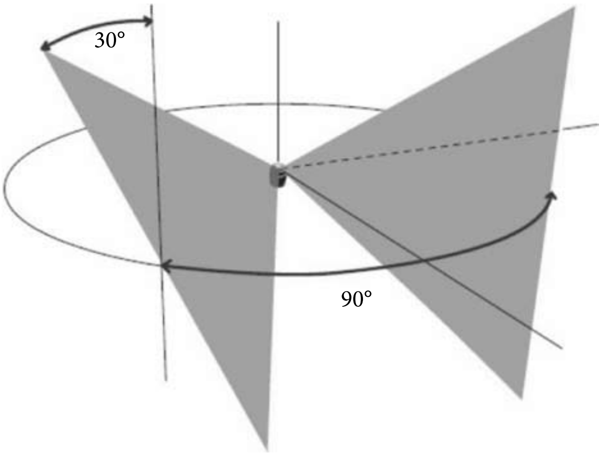

Fig. 4. The 2 rotating fan-shaped laser planes of iGPS, graphic from Metris

Fig. 5. iGPS transmitter and sensor during a test in a tunnel

6. Positioning using TOA/TDOA measurements

Various indoor localisation systems employ the Time Of Arrival (TOA) or the Time Difference Of Arrival (TDOA) methods for ranging between nodes of a network. Different types of signals are used to infer the inter-nodal distances.

6.1. Ultra sound systems

The beacons are typically static units that are mounted on the ceiling above the mobile listeners. The beacon unit broadcasts periodically ultrasonic (US) pulses and simultaneously radio frequency (RF) messages with its unique ID number. Using the TOA information from different beacons and the temperature corrected speed of sound measurement; the listener calculates its distances from the beacons. Because RF travels about 106 times faster than ultrasound, the listener can use the time difference of arrival between the start of the RF message from a beacon and the corresponding ultrasonic pulse to directly infer its distance from the beacon. The position of the listener can then be determined based on the beacons' coordinates and the measured ranges. With several distances to known reference beacons being available, the 3D coordinate position can be determined using a trilateration or multilateration technique. However, there are several disadvantages when choosing Cricket as a platform for positioning and tracking, because the ultrasound is sensitive to temperature variations and multipath signals.

6.1.1. Crickets

The Cricket nodes are tiny devices developed by the MIT Laboratory for Computer Science as part of the Project Oxygen. A 3D positioning accuracy of 1–2 cm can be reached indoors within a maximum volume size of 10 m. A Cricket board is shown in Fig. 6. The Cricket unit can be programmed either as a beacon or listener. Real-time tracking is generally possible with an update-rate of 1 Hz. The system details are given in Priyantha (2005).

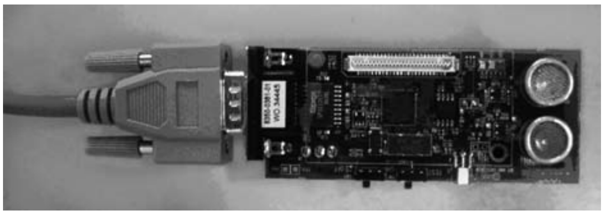

Fig. 6. Cricket unit / RS232 cable assembly

6.1.2. DOLPHIN

Distributed Object Locating System for Physical-space Internetworking (DOLPHIN) is described in Fukuju *et al.* (2003) and Minami *et al.* (2004). An accuracy of 2 cm could be reached on a test bed of 3 m in size. A prototype implementation of the nodes is shown in Fig. 7.

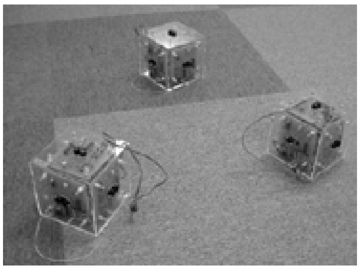

Fig. 7. DOLPHIN units, picture from Fukuju *et al.*

6.1.3. Active Bat

The Active Bat System is the pioneer work in the development of a broadband ultrasonic positioning system. It consists of roaming Active Bat tags, which transmit an ultrasonic pulse, and fixed ultrasonic receivers mounted on the ceiling. The Active Bat system measures the distance between a tag and a receiver based on the time-of-flight of the ultrasonic pulse, and computes each tag's position by performing multilateration. The Active Bat system also provides direction information, which is useful for implementing many ubiquitous computing applications. However, Active Bat employs centralized system architecture and requires a large number of precisely positioned ultrasonic receivers. The system is described by Hazas and Hopper (2006). It was shown to have 2 cm accuracy. The 3D accuracy of a synchronous receiver is better than 5 cm in 95% of cases. The principle of operation is shown in Fig. 8.

6.2. Radio frequency systems (WLAN, Bluetooth)

Symeo offers a 2D positioning system based on TDOA distance measurements in the ISM-Band (5.8GHz). Fixed reference transponders acquire the distances to rover antennas (Fig. 9). The positions are determined by a lateration technique. A position accuracy of 5 cm can be reached. The system is designed for dynamic applications, e.g. for tracking cranes and transport vehicles.

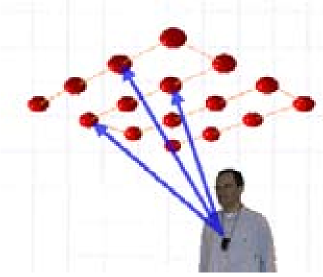

Fig. 8. The principle of the Bat Ultrasonic Location System. Picture from the Cambridge University Website

Fig. 9. Symeo antennas and transmitter, picture from Symeo

7. Positioning by signal strength

A common approach for ranging is simply to exploit the signal attenuation without requirement of clock synchronization. The Received Signal Strength Information (RSSI) is taken to estimate distances between transmitters and receivers. Various signals can be used – usually RF signals such as WLAN or Bluetooth. The location is then determined from the distance estimation form multiple transmitters by tri- or multilateration. Alternatively, for special indoor environments, an initialisation or training phase is carried out. Hereby, a rover is moved to each location and a signal-strength characteristic is derived. For position determination, the current RSSI characteristic is compared with the data-base and matched to the best fit. However, the reliability and accuracy of such a system does not meet the requirements for geodetic applications. Usually the estimated position varies by a few metres.

8. Conclusions

From the diversity of present positioning systems can follow that there is no overall solution for positioning yet. While GNSS have become the dominating system for open-sky, several systems share the indoor market; each having its own drawbacks, such as low accuracy, sophisticated infrastructures, limited coverage area or inadequate acquisition costs. The main problem is the direct line of sight that most systems require, but indoor environments hardly provide. The usage of signals that can penetrate building materials may overcome this problem in the near future.

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Research interests: positioning in wireless sensor networks; deformation analyses; detection of frequencies in geodetic data; parameter estimation, adjustment computations, engineering geodesy.