Location and Tracking in Mobile Guides

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ABSTRACT

This paper describes several approaches for tracking the mobile user of guiding systems. It illuminates different aspects for selecting the right technology, such as accuracy and costs, and illustrates the results of our projects using the specific technology.

For three examples, i.e. optical tracking, infrared-based systems and WLAN-tracking, we describe our applications from the field of indoor and museum guides. Each of the application requires specific capabilities from the technology ranging from cost-efficiency to precise measurement of position and orientation. We will therefore describe the different (dis-)advantages and draw the conclusions for the application functionality.

Categories and Subject Descriptors

H.5.2 User Interfaces: Input devices and strategies.

General Terms

Documentation, Performance, Measurement.

Keywords

Location systems, User Tracking

1. INTRODUCTION

In combination with other relevant context-parameters (such as social and physical environment, and technical and communication infrastructure [1]), an important dimension for determining the context of an entity is location data [2]. The information about the physical environment, i.e. which objects or people surround a person, what is in eyesight or in acoustic range, and where an entity (a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and the application themselves [3]) moves and its identity allows the system to draw conclusions about the current situation. By these conclusions the adaptive system can react to the context of the object, e.g. to provide a user with information about an object close to her, to show her incoming e-mails or to navigate her to a requested location. Therefore it is very important for an adaptive guiding system to determine the position of an entity most accurately in real time and to differentiate exactly between different entities. Before we describe several approaches for acquiring this information, we will define the terms of *location* and *tracking*.

1.1 Location and Localization

A location is defined as a certain place within a defined environment. In terms of *positioning* or *localization*, the system or entity determines its location within the environment by measuring distances or angles to known reference points. The system translates the relative position into absolute coordinates. This process makes use of given external information and use the location information internally. The Global Positioning System (GPS) is one example for such location systems.

1.2 Tracking

If the system surveys single entities and informs them about their position, but the entity does not participate actively in the process of localization, the term *tracking* is being used [4]. The surveyed entity cannot influence the tracking process directly. In contrast to pure location systems where the information of the position and identity is analyzed locally and not necessarily forwarded to a central system, tracking systems have a central unit that has all information of the position and identity of the entities.

1.3 Classification of Methods

There are several possibilities to classify the methods of localization and tracking. First, technological characteristics can be used to differentiate between the approaches. Another criterion is the applicability in different environments like indoor or outdoor, or the granularity of the determination of the position or the inclusion of the position together with the orientation within the physical space can be administered. Last but not least the frequency of application and its integration into current devices and into technical infrastructures can be the structural point of view.

In this paper we prefer to use the underlying technology, as the leading criterion to structure the localization and tracking approaches. First we will show approaches that make use of different kinds of light measures for tracking, and we will describe short range radio signal based methods. For three specific technologies we will describe our experience from its use in guiding systems, motivated by the different project-dependent requirements: The LISTEN-Project that required high accuracy in position and orientation, the HIPS-project that required localization and object-identification and the ICON-Guide, which relied on the existing WLAN-infrastructure at our institute. Finally, we will shortly introduce long range radio signal based methods and at least mention some other techniques like ultrasound and accelerometers.

2. OPTICAL SYSTEMS

Optical systems are equipped with cameras observing the area. Basically, we found two methods for localization and tracking: Image recognition and retro-reflection. With image recognition, positions and movements are computed from analyzing the scenery or superposed scenes. This approach falls back on complex algorithms and requires high-quality imaging, which limits the application fields and boosts costs. The method extracts features from the object in question like edges in the picture, color gradients and contrasts to identify the object. Once an object is identified, the position of the user relatively to this object can be retrieved and other information about the user's environment is at hand. Additional information about the objects can be delivered and objects in the near range can be used proactively for recommendations to the user. To reduce complexity, the search-space of possible objects can be narrowed to those objects in the current range. An example of an image recognition system has been developed and validated in [5].

The camera based A.R.Tracking®[1] system uses retro-reflecting (passive), mostly spherical markers for marking the body to be tracked (e.g. a human body or an object). These markers are recognized by the tracking cameras (image sensors, working in the near infrared light spectrum) using an infrared light flash (not visible for the human eye) illuminating the measurement volume periodically. The data of the tracking cameras are handed over to a central PC for final processing. This camera-based system is able to deliver the position and also the orientation of the marker in 6 degrees of freedom with high accuracy. Therefore, the system requires precise calibration of the cameras. Additionally, for small rooms a relatively high number of cameras is necessary. Without much doubt, both facts are cost-drivers for installation.

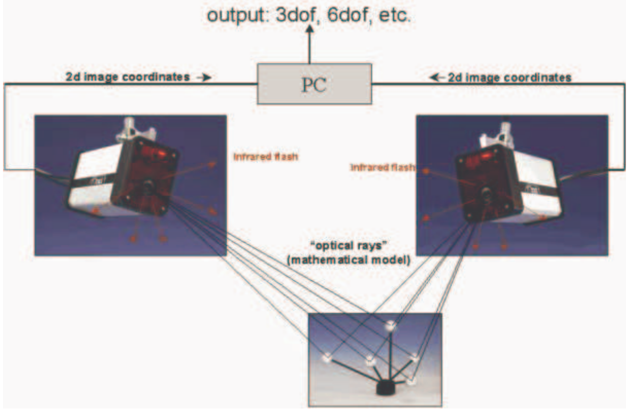

Figure 1 Principle of optical tracking of the A.R.Track-System

For indoor navigation, it allows for tracking the position of a person and the orientation of the head. For example, museum guides such as the LISTEN[2] system [6] are hence capable of exact determining the artifact the visitor is looking at.

2.1 User Location and Orientation in LISTEN

The requirements on the tracking technology arise from the goal to immerse the user into a convincing virtual acoustic scene [7]: Continuous low-latency tracking of the position of the users head and its orientation covering the entire area to be augmented is necessary. To create an immersive environment, this requires high accuracy in spatial resolution down to cm-ranges, low weight and high power-efficient transmitters, as well as high access rates up to 30 Hz. The total system latency (i.e. time interval between the head motion and the adjustment of the sound presentation) must be below 59 ms [8]. The transmit antenna shall be as small sized and efficient as possible.

Mounted upon the user's headset, the visitor of the LISTEN system is carrying the retro-reflecting markers of the A.R.Track-system. The precise tracking enables the system to determine the visitor's position and head orientation.

Figure 2 The LISTEN System applied at the Kunstmuseum in Bonn.

A central signal processing unit collects the data accumulated by receivers and calculates the absolute position and the orientation of each visitor. For determining the position in (x,y)-coordinates and the orientation angle at least four receivers with direct line-of-sight contact to the transmitters are required. In order to gain appropriate accuracy and reliability as well as to cover the whole space of a large room like in the "Kunstmuseum Bonn" (15m x 15m x 5m) eight receivers were finally deployed. With this setup the tracking system was able to measure the positions of 8 users simultaneously with an absolute accuracy of the head position of about 10 cm. The minimum granularity of the orientation angle comes to 5 degrees.

2.2 Infrared-based Systems

From its broad dispersion in remote controls, consumer and monitoring electronic, infrared-transceivers (transmitter and receiver together) are cheap, small and energy-saving. From this point of view, IR-technology is predestined for the use in ubiquitous computing. On the other hand, IR-technology always need direct indivisibility between transmitter and receiver, the range is limited, and the infrared-signal is reflected by walls, floors and exceedingly by windows. Additionally, interferences with other natural (direct sunlight) and synthetic emitters cut down the bandwidth.

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[1] The ARTracking homepage (August, 2005): http://www.ar-tracking.de

[2] LISTEN was funded as an EU-IST project with the contract No.1999-20646

2.2.1 *Active badges*

In 1992, Olivetti Cambridge Research Labs (today AT&T Cambridge) pioneered active badges[3], clip-on computers that identify themselves to receivers placed throughout a building. The badges send an infrared signal each 10 seconds submitting the identifier. The receivers of the signal submit the identifier to a main computing station whenever it recognizes an active signal. The accuracy of the detected position depends on the number and dispersion of receivers, e.g. if one exists in each room of the building, the abstract room number can be determined. The quality of measurements allows tracking single persons in large rooms, checking who is present in the room, or who is sitting next at the table. The information level is sufficient to open doors automatically, or to greet people by name when entering the room. In large rooms, the system is capable to process several receivers.

Figure 3 Four generations of active badges

2.2.2 *IR-Tacking in the HIPS-Project*

In the HIPS[4] project [9] we developed a mobile guide for the castle situated in our campus. Infrared emitters attached to pictures exhibited in the castle were used to locate the user and generate personalized tours or navigation hints. About 50 special IR-emitters were designed and manufactured to cover the complete ground floor of the exhibition: 5 rooms, one vestibule, and two chapel rooms. Two types of emitters were used: localization emitters for the exhibits with a narrow angel of signals to identify the relation between the visitor and the exhibit, and connection emitters for the doors/corridors between the rooms with wide angels of signals to identify the navigation of the visitor in the physical space. The IR-signals were received at the mobile device of the visitors, transmitted to the central server via WLAN, and used to continuously identify the position of the visitor in the exhibition space. The result was exploited in two ways: The visitor arriving in front of an exhibit, i.e., entering the cone of the IR-emitter, gets a sound-icon (an "earcon") to lead the attention of the visitor to the screen, where the visitor could click on an icon to receive a thumbnail of the exhibit(s) she is in front of. The presentations of other exhibition content were not interrupted during the IR-announcement of new items in order not to disturb the visitor during the study of content presentation by earphones.

The second way to exploit the IR-results was an indication of the visitor's position in the physical space of the exhibition (see Figure 4).

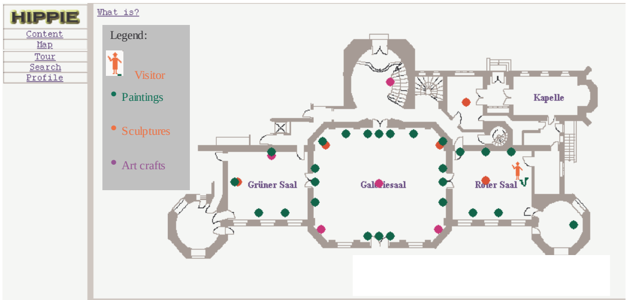

Figure 4 Map of the exhibition with IR-locations

For the localization of the visitor the IR-emitters could be manipulated with respect to the length of the transmission signal and with respect to the transmission angle to cover the whole physical space but also to avoid too much overlap of the signal map. Best results were achieved with "blinders" at the receivers at the visitor's mobile device to reduce the reception angle from the side of the current orientation of the visitor. Experiments with an additional electronic compass integrated into the receiver of the visitor revealed that the electronic compass was not necessary for the identification of exhibits but it was very helpful for the feedback of the visitor's orientation on the map. Visitors could better plan their navigation in the physical space if the line of sight was displayed on the screen together with the position.

3. SHORT-MIDDLE RANGE RADIO SIGNALS

Short-middle range radio signal transmissions are applied to cover dedicated spaces for data delivery and communication. WLAN in office buildings are the most prominent current example of such infrastructure. Ultra wide band signals are another example dedicated for localization purposes.

With the same bandwidth and similar costs compared with infrared, the most important advantage of radio frequency based technology is the needlessness of the direct indivisibility between sender and receiver. Since RF-signals pervade most materials of building, the range is superior (up to more than hundred meters). On the other hand, reflection and reduction of the signal strength affect the accuracy adversely (1 to 3m; [4]). Other aspects to be considered are the regimentations for frequencies and power.

3.1 Cricket

Beside low-cost application, heterogeneous networking and room accurate location, the Cricket system [10] developed at the MIT Lab, Cambridge focuses on decentralized administration and privacy protection. Instead of a central computer, each of the devices should localize its position themselves. Therefore, stationary beacons emit RF-signals delivering its identifier, and the receiver computes the current position of the device. It is finally up to the device whether to only use the information locally, or to transmit the information to remote services.

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[3] The Active Badges homepage at AT&T Laboratories Cambridge (April, 2004): http://www.uk.research.att.com/thebadge.html

[4] HIPS was funded as an EU-Esprit project with the contract No.25574

The reliability of the determined room is 95% [10]. If the relatively rough calculation satisfies the application requirements, then the Cricket system provides a scalable positioning system due to the decentralized approach.

3.2 WLAN Tracking

Since Wireless LAN (WLAN[5]) is available for data-transfer at more and more locations, the progress in tracking devices equipped with WLAN based on the signal strength or run duration establishes new opportunities for user-tracking. This allows reducing the costs because the hardware (e.g. access points, WLAN-cards) can be used for both purposes: Data-transfer and positioning.

The first method is based on the fact that signals lose intensity while spreading out in an environment. From measuring the strength at the current position, the distance to the sender can be determined, and triangulation allows for determining the position from several signals. This method assumes a positive correlation between signal strength and distance to the base station. The disadvantage is a high measuring error caused by dynamical changes in environment, such as shielding of the signal by objects or people. To reduce this error, the fingerprint method uses signal fingerprints. Each unique fingerprint identifies a unique position in the room. In large rooms, signal patters of the fingerprints recur. Therefore, both methods are usually combined.

Obviously, the fingerprint-approach requires the creation of radio-maps (an example is shown in Figure 5) in advance, where the signal strengths are measured by hand at different positions. For the field trials of Microsoft's RADAR system [11], for example 70 measurements at different points were necessary to create the radio-map for one floor of the Microsoft Research centre.

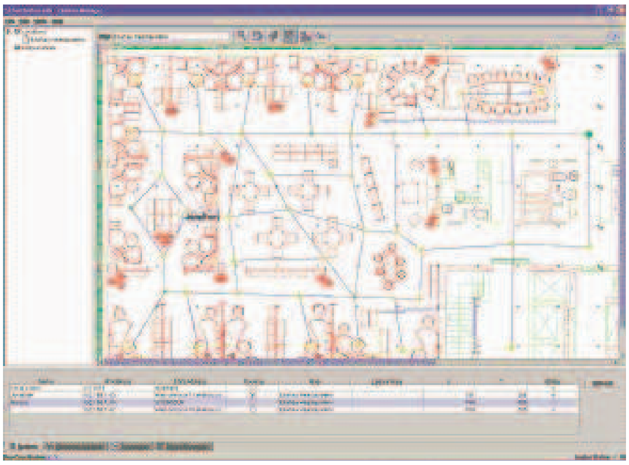

Figure 5 Position model of the Ekahau Manager

Due to changing physical conditions and shielding by objects or moving people, the accuracy of systems like the Ekahau Positioning Engine is between 3 and 4.5 meters. For the Smart Library[6] study, this system was applied to the library of the University of Oulu, Finland. The user of the system used a PDA for browsing and searching the catalogue and for being guided to the shelves. All male and 64% of female users rather use the interactive system than the classical way of numbered shelves.

3.3 Tracking for an Indoor-Guide

The mobile guide for our research department was developed for supporting visitors of our institute, for demonstrating our expertise in mobile computing, positioning technologies and human-computer interfaces. Hence the requirements for the prototype were:

- Present information about our research department (employees, projects)
- Let the user experience indoor navigation on our floor.

For navigation support, the current position of the user is regularly updated on a map on the PDA, as soon as a new position is available on the positioning server. If the user wants to meet with someone or go to a specific place, he can hit the navigation button located in the map viewer toolbar and will be offered a new dialog window to select the destination (by selecting the label of one of the graph's nodes). Then, the path finding module will find the graph node closest to the current position and return the shortest route to the desired destination as a sequence of nodes. A SVG polyline representing the recommended route will be displayed and the points attribute set to the nodes coordinates. A thread re-computes the shortest route again and again, until the user arrives his destination or stops the navigation by pressing again the navigation button.

To be tracked, a device has to run a small application (Ekahau Client) that reads and forwards the signal strength measurements to the Ekahau Positioning Engine (EPE), responsible for gathering the fingerprints from the mobile devices and computing their position. The company offers also WiFi tags to track devices or persons that do not have a build-in WLAN card[7]. Because the current position of the users is centralized computed on the server, clients need to connect to the server via TCP/IP. Therefore, a location thread is created at startup to open a socket connection to the middleware server, which must be specifically configured to work with either Ekahau or Ubisense (cf. 3.4) and can not work with both of them at the same time (no sensor fusion). The server forwards position information (as X-Y-Z coordinates) to the thread as soon as new data is available and the thread updates the x-y-z attributes of the buddy on the map. Since the same floor map is used for both Ekahau and Ubisense, some additional conversion is needed on the PDA to get the absolute coordinates.

A key factor in the success of the WLAN positioning is the rate at which new measurements of the signal strengths can be made. This depends to a great extend from the type of WLAN card and the driver. WLAN was not designed to be used for positioning

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[5] WLAN: wireless local area network; standardized wireless network technology based on IEEE 802.11

[6] The Smart Library brochure (April, 2004): http://www.ekahau.com/pdf/SmartLibrary_Brochure.pdf

[7] A list of supported WLAN cards can be found (April, 2005) at http://www.ekahau.com/products/client/devices.html

purposes, therefore many cards are not built to allow a fast access to the signal strengths (some drivers even don't allow accessing signal strengths at all). In particular, many PDA internal WLAN cards have a very bad scan speed, which means that an additional CF/SDIO WLAN card is usually needed to get a viable tracking of the device.

3.4 Ultra Wide Band (UWB)

Multi-path distortion caused by radio signals being reflected from walls or people is a big issue in RF positioning and a source of inaccuracy. Thanks to the short duration of UWB pulses, it is possible to filter the reflected signals from the original signal, thus resulting in higher accuracy, about 15 cm.

To be tracked, the user must wear a registered UWB tag. The installation of the Ubisense[8] system for a single room (also called a cell) consists of four sensor units mounted at the corners and a control unit. The sensor units' timestamp the signals from all tags present in the cell and forward them to the control unit that computes the position of the tags using TDOA (Time Difference of Arrival) and AOA (Angle of Arrival).

4. LOCALIZATION with LONG RANGE RADIO WAVES

Probably, the most predominant system is the Global Positioning System (GPS). GPS is a time measurement based system and can be applied in almost all open space environments except from narrow streets or covered sight to the sky due to trees or other obstacles to receive the signals from at least 4 satellites. The accuracy of the localization can vary between 3 and 10 meters depending on the satellite connection and the continuity of the navigation of the receiver. The accuracy can be increased by so called Differential GPS (D-GPS) by terrestrial stations to a accuracy of 2 to 5 meters. GPS installations are for free but receivers are still expensive and are therefore limited to be introduced in mass-market devices.

Another upcoming solution is locating users by signals of their GSM mobile phones. However, the accuracy of this localization method is quite crude and subject to huge variations. In particular in rural areas with wide phone ID cells the accuracy is not acceptable. With the advent of the third generation mobile standard UMTS, the accuracy of localization will improve significantly. However, privacy issues play an important role here and might hinder a wide spread use of this localization method.

5. ULTRASOUND-BASED SYSTEMS

Ultrasound-based systems emit sound waves beyond the human perception. For that reason well established systems use frequencies of about 40 KHz. In this frequency range three to ten meters can be resolved. The relatively slow velocity of the propagation of sound (~ 343 m/s) allows for a high accuracy with a relatively low sampling rate. The resolution of a commercially available sound card with a sampling rate of 48 KHz allows a theoretical resolution of 1 cm, making ultrasound-based systems quite suitable.

The main disadvantage of ultrasound-based systems is their interference by environmental changes. Fluctuations in the atmospheric humidity or of the room temperature for example cause deviations in the propagation speed of up to 3%. Empirical studies investigating the influence of sound reflections on most surfaces have proved that a 40 KHz signal is oscillating 20 ms in a room [12]. This echo effect requires additional effort in measuring and calculation to avoid inaccuracies.

5.1 Active bats

Active bats[9] is a real time based system from AT&T using ultrasound to localize its badges (more precisely bats). The label "active bats" is derived from the bat using ultrasound for its chase and navigation in the dawn. A radio based request causes the bat to send its ID to a network of receivers on the ceiling. These receivers calculate the propagation of the signal and send them to a central unit, which calculates the precise position of the bat via multilateration (the fixing of a position by reference to the time difference of arrival of a signal at a collection of sensors). Statistic methods allow eliminating measuring errors caused by reflections of the ultrasound signal.

The resolution of the system is about 9 cm in 95% of all measurements. But this high precision is to be put into relation to the high expenditure in installing numerous receivers at exact positions (each 10 m^2 of ceiling needs one receiver) and the need for high computing power. Scalability and high installation costs are the most relevant downside to this solution.

6. OTHER TECHNOLOGIES

There are additional technologies used for localization like accelerometers worn at the foot or the hip to identify the movement of the user and correlate the movement with a model of the physical space. Accelerators or other localization techniques can be combined with an electronic compass to identify the orientation of the user. RFID technology is a candidate for localization purposes in logistical context for goods; it can also be used for people wearing a RFID-Reader. Currently the lack of RFID-Readers integrated in mobile devices like PDAs or mobile phones reduces the applicability of RFID for localization of standard users.

7. CONCLUSIONS AND FUTURE WORK

In this paper we illustrated different tracking technologies we consider to be useful for mobile guides. For camera-based optical tracking, infrared beacons and WLAN-tracking we explained our experience gained from past projects in more details. From the high-quality measurement of position and orientation, to simple and cheap IR-setups and upcoming WLAN-tracking we described applications fitting well to the capabilities of the technology.

In the sensor-lab at our institute we will proceed to work with different tracking systems. Beside the introduction of new technology, such as RFID, the main issues are to hand over between tracking systems (e.g. to hand over to a more precise WLAN-tracking system when the user enters the building and leaves the range of the GPS), and to combine tracking

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[8] The Ubisense homepage (August, 2005): http://www.ubisense.net/

[9] The Active Bat homepage at AT&T Laboratories Cambridge (April, 2004): http://www.uk.research.att.com/bat

information. By integration of RFID with WLAN-tracking, we will for example be able to identify persons use enhanced personalization methods for the tracked person.

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