Sensor Data Fusion for Location Awareness

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INTRODUCTION

In pervasive computing environments, location is essential information as it is an important part of the user's context. Applications can exploit this information for adapting their behavior. Such applications are termed location-aware applications (e.g., friend-finder, asset tracking). The location of a user is derived by various positioning methods. Especially for indoor positioning, different approaches have been proposed. The majority of indoor positioning systems rely on different technologies, usually of the same kind, like wireless LAN signal strength measurements (Bahl & Padmanabhan, 2000), IR beacons (Sonnenblick, 1998), or ultrasonic signals.

At this point we will quote the definitions of accuracy and precision, the most important characteristics of a positioning system:

- Accuracy denotes the distance within which the system has the ability to locate a user, for example, 1-10 meters.
- Precision denotes the percentage of time the system provides a specific accuracy, for example, 80% of the time the system provides accuracy 1-5 meters (or else accuracy less than 5 meters).

The accuracy and precision are tradable, and it is clear that if we need less accuracy, the precision that the system provides increases.

During the past few years, several location systems have been proposed that use multiple technologies simultaneously in order to locate a user. One such system is described in this article. It relies on multiple sensor readings from Wi-Fi access points, IR beacons, RFID tags, and so forth to estimate the location of a user. This technique is known better as *sensor information fusion,* which aims to improve accuracy and precision by integrating heterogeneous sensor observations. The proposed location system uses a fusion engine that is based on dynamic Bayesian networks (DBNs), thus substantially improving the accuracy and precision.

BACKROUND

Indoor positioning systems have been an active research area since the Active Badge Project (Want, Hopper, Falcao, & Gibbons, 1992). Since then, several indoor location systems have been proposed. A large number of them use IEEE 802.11 (Wi-Fi) access points to estimate location. RADAR (Bahl & Padmanabhan, 2000) is a radio-frequency-based system for locating users inside buildings. It operates by recording and processing received signal strength (RSS) information. The RSS method is used also by the commercial system Ekahau (Ekahau Positioning Engine).

The Cricket Location Support System (Nissanka, Priyantha, & Balakrishnan, 2000) and Active Bat location system (Harter, Hopper, Steggles, Ward, & Webster, 1999) are two systems that use the ultrasonic technology. Such systems use an ultrasound time-of-flight measurement technique to provide location information. They provide accurate location information, but also have several drawbacks like poor scaling and a high installation and maintenance cost. For these reasons they are rather inaccessible to the majority of users.

Another category of location systems uses multiple sensor readings (Wi-Fi access points, RFIDs) and sensor fusion techniques to estimate the location of a user. Location Stack (Graumann, Lara, Hightower, & Borriello, 2003) employs such techniques to fuse readings from multiple sensors. Another similar approach is described in King, Kopf, and Effelsberg (2005). The drawback of these systems is their inability of supporting mobile devices with limited capabilities (CPU, memory) as the location estimation is performed at the client side; hence devices incur the cost of complex computations.

The location estimation system described in this article relies on data from sensors to determine the location of a user. Our work differs from previous approaches in various aspects. Firstly, we use dynamic Bayesian networks for location inference. By using DBNs, we obtain better location estimation results. Along with heterogeneous sensor data that are processed in real time, we can also "fuse" past information about the user. Secondly, our system can support a variety of mobile devices (PDAs, palmtops) with low computing power. Location estimation takes place in a server residing in the fixed network infrastructure. Mobile devices are just transmitting observations from sensors to this server and receive the location estimations. Finally, the adopted system architecture has the advantage of easy management and scalability (e.g., the installation of a new access point is completely transparent to users).

POSITIONING TECHNOLOGIES

In this section we present the principal technologies that are used for indoor positioning and describe their characteristics. We also discuss a categorization of the devices.

The most important wireless LAN standard today is the IEEE 802.11 (Wi-Fi) that operates in the 2.4 GHz ISM band or 5GHz band. This technology is used by several positioning systems that measure the signal strength from access points (RSS) to locate a user.

Radio frequency identification (RFID) is the technology used for security tags in shops, ID cards, and so forth. Tags are powered by the magnetic field generated by a reader and transmit their ID or other information. Such tags do not require any battery and can be deployed in a building to detect object and person passing or proximity.

Infrared (IR) beacons are programmable devices that periodically emit their unique ID in the IR spectrum. Usually the range of these beacons is approximately 10-20 meters, and the infrared receiver should have line of sight with the beacon in order to receive its ID.

Ultrasonic signals are vibrations at a frequency greater than 20 kHz. The devices used to receive and transmit ultrasonic signals are called transducers and are commonly used for distance measuring. In general, they integrate a sensor that can receive or transmit an ultrasonic signal and another RF transmitter/receiver which is used for synchronization.

All the previously mentioned devices (elements) of different technologies (access points, beacons, tags, etc.) can be found in indoor environments either deployed in the building or attached to mobile devices. Some of them emit information, and others detect (read) information. According to their position and functionality, the elements can be categorized as follows:

- Portable elements are those carried by users or attached to their mobile devices (RFID tags, Wi-Fi adapters)
- Infrastructure elements are those attached to the building (Wi-Fi access points, IR beacons, RFID tag readers).
- Active elements (sensors) are those which detect a phenomenon or take measurements (RFID tag readers, Wi-Fi adapters).
- Passive elements are those that emit information which is detected by active elements. Wi-Fi access points, IR beacons, and so forth fall into this category.

SYSTEM ARCHITECTURE

The architecture of the proposed location estimation system is organized into three layers: the sensor layer, the collection layer, and the fusion layer. Figure 1 illustrates the generic architecture of the proposed system. In the same figure are also depicted location-aware applications which exploit the location information and databases where the personal profile of users and historical data about their behavior are stored.

Figure 1. Architecture of the indoor location estimation system