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# A Location System based on Sensor Fusion: Research Areas and Software Architecture

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**Abstract:** Information about the current position of a mobile device is required by context-aware applications. An inexpensive, pervasive, all-purpose location system is not yet available. This paper discusses approaches of different location systems and provides an insight in our ongoing research work, in particular for indoor locations.

## 1 Introduction

Position has long been identified as key information required for context-aware and location-based applications. In recent years a significant amount of research effort has aimed at inventing an all-purpose location system. Unfortunately, only the Global Positioning System (GPS) has achieved public acceptance. GPS is an outdoor location system. It is easy to use, free of charge, GPS receivers are relatively inexpensive, and it provides adequate accuracy for most outdoor applications. However, an inherent flaw of GPS is that it does not work indoors where people of developed countries spend most of their time.

Indoor location systems are still a research issue today. Many of the research systems do not scale well because they require an expensive infrastructure or a complex calibration process. Only few indoor location systems offer an accuracy of a few meters. For a large class of location-based applications, such as finding a book in a bookshelf, this accuracy is still insufficient.

New research directions in indoor location systems try to exploit the existence of more than one sensor to determine the location of a mobile device. This technique is called sensor fusion, and first publications in this area are promising. Another interesting research area is how to integrate Wireless LAN and Bluetooth access points as sensors into location systems. Using readily available infrastructure is a great benefit, especially Wireless LAN and Bluetooth show nearly complete coverage of areas where people of industrialized countries live. Additionally, other sensors that could be employed to sense the location of a mobile device might be integrated into a location system based on sensor fusion.

This paper is organized as follows. In Section 2, we discuss related work and present current research areas. Section 3 outlines interesting location sensors, location determination algorithms and sensor fusion algorithms. In Section 4 we provide an overview of the software architecture we are using to implement our research ideas in the area of location systems. Finally, we conclude the paper in Section 5.

## 2 Research Areas and Related Work

Indoor location systems have been an active research area since the Active Badge [1] project in 1992. Since then, several different indoor location systems have been invented as a counterpart of GPS to fill the gap in indoor positioning systems. These indoor location systems offer various capabilities but also different disadvantages [2] [3]. Most of them require additional infrastructure to be operational. In this paper we focus on location systems

and location sensors that are available as commodity products, as all the specialized hardware-based approaches are too expensive and hence do not scale well.
Only a few all-purpose location systems utilizing one technology to sense the position of a mobile device are available [4]. One of the recently proposed location systems called Place Lab [5] supports different sensor technologies and until now sensors based on Groupe Spécial Mobile (GSM) cell phones and wireless LAN technology are evaluated.
If a location system is split into coherent pieces, two major parts can be identified: sensors to sense a certain physical attribute and an algorithm to compute a position from the values delivered by the sensor. Recently published location systems add as a third part a sensor fusion algorithm that combines position estimates obtained from different location determination algorithms and different sensors. The idea is that the results generated by a sensor fusion algorithm are more precise than a position estimate provided by one kind of sensors.

# 3 Sensors and Location Determination Algorithms

Our goal is to integrate multiple sensors into our location system to determine the location of a mobile device. We assume that the mobile device in question is equipped with the appropriate sensors. As an outdoor sensor we have chosen GPS, Wireless LAN and Bluetooth technology were selected as indoor sensors.

## 3.1 Global Positioning System

The well-known Global Positioning System (GPS) was designed for the usage of the U.S. military to compute the position, speed and time of a GPS receiver [6]. The GPS infrastructure is funded and controlled by the U.S. Department of Defense, and is fully operational since 1995 as a worldwide, satellite-based navigation system. The nominal GPS Operational Constellation consists of 24 satellites which orbit the earth at a height of approximately 20,000 km. Usually, more than 24 satellites are operational as new satellites are launched to replace old ones. The Standard Positioning Service of GPS provides an accuracy of a few hundred meters for civil usage.
To improve the accuracy of GPS a technology called differential GPS was developed. The GPS signal is usually blurred by noise, bias, and blunders. To calculate correction data for mobile receivers positioning errors are measured at well-known locations, and the correction data is spread via satellites, FM sub-carrier broadcasts and others. This correction data is used by mobile receivers to adjust their own position measurements. With this improvement a positioning accuracy up to one meter can be achieved. A clear line of sight to at least four satellites is required to calculate the position (longitude, latitude, and altitude) and time of a GPS receiver. GPS signals can be blocked by obstacles such as walls, foliages, and clouds. For example, "urban canyons" formed by skyscrapers prevent GPS receivers from receiving signals emitted by GPS satellites.
Within our research work we integrate GPS as one sensor to our sensor fusion based location system. To create an all-purpose location system an outdoor sensor is needed.

## 3.2 Wireless LAN

An early approach of Wireless LAN technology as a sensor for location systems was published by Bahl and Padmanabhan during their work for the RADAR project [7]. In their approach mobile devices continually measure the signal strength of beacons that are periodically emanated by fixed access points. To obtain usable results each point of the terrain must be covered by at least two access points. Before the system can be used for user tracking, a database with signal strength values at well-known locations must be built. The location of a mobile device is estimated by comparing the strength of the last measured sample with values stored in the database. The authors propose a single nearest neighbour in signal space, a k-nearest neighbours and a Viterbi-like algorithm to estimate the location of a mobile device. Real world indoor evaluations have shown that a median error distance of 2.37 meter can be achieved [8].

In [9] the authors are mainly interested in location determination algorithms that perform well in case of minimal calibration data. They used a technology called Place Lab as a metropolitan-scale Wireless LAN location system. The idea behind Place Lab is to utilize the huge databases created by the war-driving community to estimate the locations of access points. The term war-driving was firstly defined by Pete Shipley [10] and means driving around looking for wireless networks. One of the largest war-driving databases available free of charge contains more than 2.26 million entries of access points worldwide [11]. Place Lab utilizes the positions of access points in communication range of a mobile device to infer the location of the device. The benefit of this approach is that it spreads the costs and effort to build the database over a large community. A Bayesian algorithm proposed by the authors has shown a median error distance in a real world outdoor evaluation of 10-30 meters.

Based on the promising results of Wireless LAN technology as a sensor for location systems, we investigate how war-driving databases can be employed to create a highly accurate indoor location system. In addition to that, we integrate the Place Lab technology as an outdoor sensor to improve the accuracy.

### 3.3 Bluetooth

Bluetooth was developed in 1999 as a cable replacement technology. The usual communication range of Bluetooth devices is only a few meters. However, it is an interesting technology for location systems because it might provide fine-grained position estimates. In [12] the authors investigated the usability of Bluetooth for location systems. Depending on the class of Bluetooth devices used and the velocity of the moving device, the amount of time needed to find surrounding devices can be higher than the time the devices are in communication range of each other.

We believe it is the right time to methodically investigate how Bluetooth can be used for location systems. Especially, since the Bluetooth Class 1 and Enhanced Data Rate specifications are available. Communication range is increased to 100 meters by the former specification, and the latter specification enhances the data rate to 2.2 MBit/s.

### 3.4 Sensor Fusion

In practice, a location system may consult many different location sensors to determine the location of a mobile device. In many cases, though, sensor data is noisy and misleadingly influenced by the environment. Even worse, position estimates from different sensors may conflict with each other.

Sensor fusion is a promising technique to solve position estimate conflicts reported by different location sensors. Additionally, this technique may improve the position accuracy. In [13] a Bayesian network algorithm shows how to minimize the number of queried sensors while simultaneously achieving a certain level of accuracy. Unfortunately, in the evaluation process only homogenous sensors are used. In contrast, the Place Lab project utilized Wireless LAN access points, GSM mobile phone cell towers and a sensor fusion algorithm based on particle filters to improve the accuracy and coverage of their location system significantly [11].

# 4 Software Architecture

The software architecture of our location system is divided into two parts: a small piece of native code and a Java 2 Micro Edition (J2ME) part. Sensor data such as signal strength values are usually not directly accessible through Java because these parameters are stored in an operation system dependent way and managed inside the hardware drivers. Therefore, a small native code library gathers sensor data and offers the values to the Java applications. Location determination and sensor fusion algorithms are implemented using Java to exploit the write-once-run-everywhere capabilities of Java. We have chosen J2ME because for most Laptops, PDAs, Smart phones and mobile phones a J2ME virtual machine is available. The native code implementation and the Java application are tied together with the Java Native Interface.

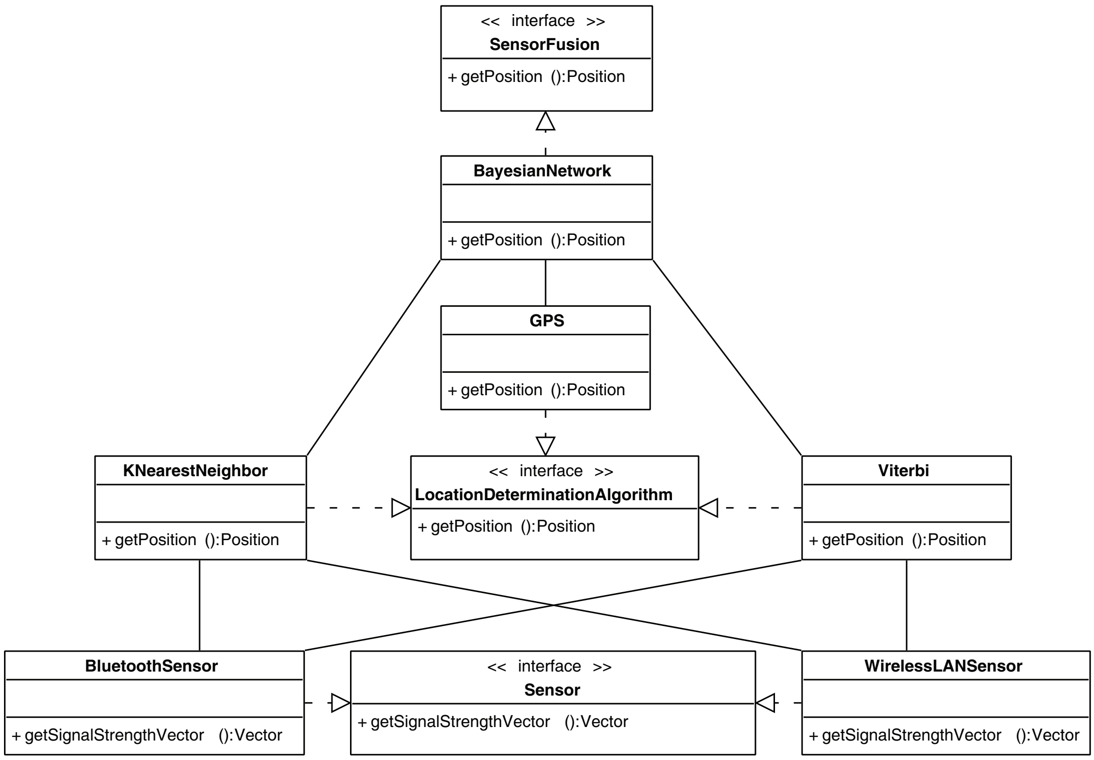


**Figure 1: Software architecture**

Figure 1 shows the software architecture as an UML class diagram. The three elements of a location system, as identified in Section 3, divide also the software architecture. The sensors, location determination algorithms and sensor fusion algorithms are represented by the *Sensor*, *LocationDeterminationAlgorithm*, or *SensorFusion* interface, respectively. Each algorithm and sensor implementation has to realize the interface to which it belongs. The interfaces define generalized methods that can be used for a standardized data exchange. For instance, the method *getPosition* is defined in the *LocationDeterminationAlgorithm* interface and implemented by location determination algorithms, such as *KNearestNeighbour*, *Viterbi* and *GPS*.

# 5 Conclusions

Similar to other wireless technologies such as FM radio, satellite television, or mobile phones, an all-purpose location system has to provide full coverage in areas where people live. A

distinction between out- and indoor is inappropriate for its future use, especially if location-based and context-aware applications raise the markets as forecasted by various research institutes.
In this paper, we have presented promising technologies for position determination and we have shown that an all-purpose location system based on sensor fusion will be feasible. Currently, we are working on an implementation of such a location system as part of our on-going Mobile Business project.

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