# Synergetic Positioning Architecture for Location-dependent Services

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## Abstract

*Positioning has been a driving factor in the development of ubiquitous computing applications throughout the past two decades. Numerous devices and techniques have been developed — few of them are actually used commercially. Within the NOMAD [4] project, multiple methods are being combined to recalibrate each other by means of data fusion. A novel architecture processes the data from pervasive devices penetrating everyday objects to the cheapest level. The synergetic heterogeneity of completely different recognition principles allows to tailor the perceived positioning probability to the specific requirements of the target application.*

## 1. Introduction

*Location Awareness* in general describes applications in computing and telecommunication, which alter their behaviour in dependence of the location of an entity [1]. Such location represents a major category of *context*, and is derived by various methods of *positioning*. *Authentication* is an issue implicitly related to certain methods of positioning, employing the same technology.

Despite years of experimentation in the labs, very few positioning technologies have currently significant economical impact – most prominently GPS. Many other technologies, for indoor as well as outdoor, have niche markets only, if commercialised at all. Reasons include high costs compared to the added value achieved, or immature precision and reliability.

By principles of data fusion [2], a novel architecture massively *combines* multiple individual positioning technologies to obtain more precise and more reliable results accourding to the various needs of the whole range of loaction based services.

An increasing number of technologies suitable for positioning is becoming available. We are at the advent of the penetration of everyday objects with pervasive devices to the cheapest level. Reliable, camera-based visual tracking and shape/face recognition becomes very feasible with falling costs of the imaging components. Biometric devices might arrive in every office. Wireless and wired sensor networks of a variety of categories can detect presence and proximity of people and objects. Position information can be derived from sources not previously designed for this purpose, such diverse as triangulations in wireless communication networks (Wifi, GSM), sightings of campus cards at cash registers, usage of IP or MAC addresses at certain wired network patches, etc.

The interworking of all these systems will provide a *synergetic approach* of positioning and a new quality of context awareness. An *architecture* harnessing the parallel data streams from all these sources for positioning is presented in this paper, leading to a new level of precision and well-structured confidence in the data presented to the respective applications.

The heterogeneity of the recognition principles being included, used in a synergetic manner, allows to tailor the perceived positioning probability to the specific requirements of the target application, at the time present and in predictable near future, as well as their interactions and the elimination of wrong and misleading information by self-healing and self-learning.

## 2. Synergetic Positioning Architecture

We assume that the whole avalanche of ubiquitous computing devices of most different kinds that is set to arrive in our lives can be exploited for positioning purposes – even if not originally built for this – and supported by a number of dedicated positioning systems. It is the combination of all of them, delivering small pieces of information into a mosaic representation of the real life.

Naturally, not all of this information will be correct, as different classes of errors occur:

- Uncertainties in the actual position,
- Atypical deviations of temporal validity,
- Change of relations between objects.

The approach of *synergetic positioning* leads to a large amount of sensing nodes contributing to the whole image, including the consideration of misleading and wrong information from individual nodes, and the accumulation of history data from previous sightings for the learning process.

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## 2.1. Input channels

Listing a number of possible channels below provides examples in the context of synergy, not completeness. Naturally, different combinations of such channels will be exploited at different locations, indoors and outdoors:

- *Global Positioning System* (GPS), as it becomes increasingly available in ubiquitous devices,
- *RFID* (Radio Frequency Identification) gates (like doors), readers in/at container objects (desks, briefcases)
- *Ultra wideband RF* and *Ultrasonic* positioning,
- Cameras *tracking* contours *visually*,
- *Weight-measuring floors*, or sensor *carpets*,
- *Wireless sensor networks* (WSN) measuring proximity of people,
- *Active badges* for places where the obtrusiveness of these devices counts as positive argument,
- *Biometric* sensors, providing a high level of confidence, used punctually,
- *Wifi cellular positioning*, with or without additional hardware for more precision,
- GSM and beyond *cell and sub-cell positioning*,
- *Location inference*, i.e. all software approaches based on already existing systems (e.g. wired ethernet patches, the proximity of Bluetooth devices, smart cards used at stationary stations).

Obviously, the best effects are expected from the most different kinds of principles of positioning, thereby being most complementary.

## 2.2. Architecture

Figure 1 presents an architecture for the synergetic positioning. It features an arbitrary number of different *input channels*, each representing a large number of sensing devices of a common positioning technology, as discussed above.

The heterogeneity of these input channels requires *preprocessing* tailored to the specific technology. E.g., a technology generating large numbers of sightings might apply an early aggregation of data. The video tracking or face recognition might have the tracking and recognition process encapsulated there, outputting room vectors of sightings, or extracted standardised visual features.

In the preprocessing, *privacy filters* can be implemented. E.g. a video tracking camera might have a mode prohibiting face recognition, or RFID readers could contain a blacklist of items not to be scanned.

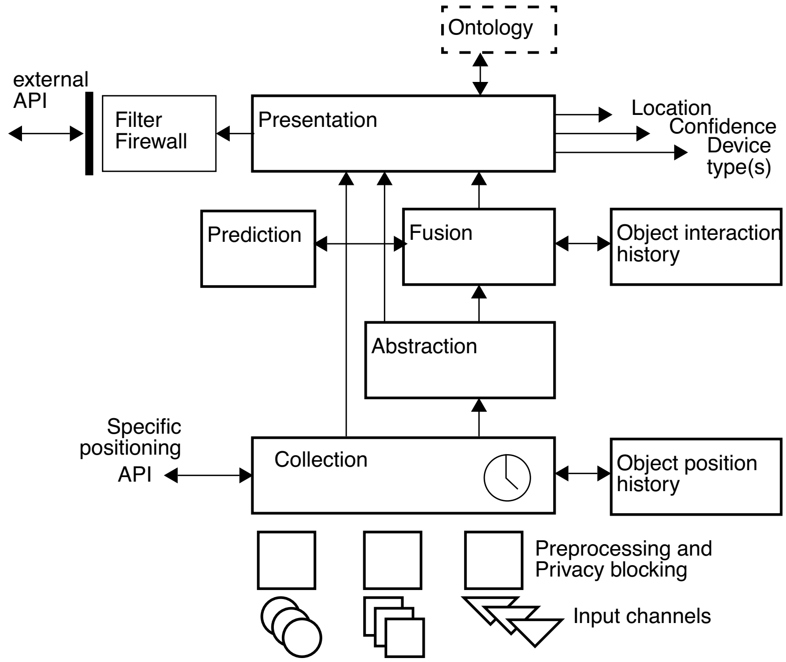


**Figure 1 Architecture for redundant positioning**

The goal of that early filtering is to avoid protected data to accumulate in history buffers appearing in upstream modules.

The preprocessed data are forwarded to the *collection* module, providing a "plug-in" socket for each input channel. Scans will be *time stamped* here, if not been stamped in their originating positioning system. Time stamping is crucial to compare data from different sources, and for applications to determine if there is a location determination lag. The format of the data is not unified at this point – it would be normal to expect multiple, incomparable formats. On the collection level, a *history of object positions* is important to be kept.

The *abstraction* module changes the location data (if necessary) into a site specific form as a default operation. The primary goal is to present the data in a unified, object-oriented view.

The *fusion* module combines data from multiple sightings on multiple location systems. Employing the provided redundancy at this level leads to potentially improved accuracy. At the fusion level, it is possible to store a *history of object interactions*, i.e. preliminary assignments of objects to other objects and objects to people, to observe regular patterns and routines, e.g. what items a person regularly wears, what valuables typically go with which owner.

This history is the prerequisite for the *learning* process, which than can lead to *predictions* of probable interactions in the future.

The *presentation* level must provide everything an application could possibly need. In location based services it is often equally important to locate a device as well as the person using it.

Previously proposed approaches of fusion [3] obscure/abstract location data to a level where useful information is lost (e.g. the type of devices that have been located and have been part of the fusion process, or the reason for assigning a certain confidence level). This hinders the application to ask different questions, e.g. the question “Where is Tom?” might be answered by an aggregation of sightings of items regularly worn. Having such sightings fused with details lost would make it impossible to answer Tom’s question “Where is my PDA?”. Avoiding this problem, our approach allows the presentation level to communicate with pre-fusion levels, such as collection and abstraction.

On the output side, beside the location itself, the confidence level, and the type of confidence expressed in the type of the providing device are presented.

So far, the system has been restricted to timed location as a subclass of context. Whether introducing other subclasses and background knowledge of the surrounding world – as indicated with the *Ontology* module – improves the positioning, is being investigated.

For any external access, a *filter and firewall* module restricts access to an allowed amount of information, which can be adjustable to the degree of authentication the querying party provides.

## 3. Implementation

The approach of synergetic fusion for positioning and authentication is being followed from the theoretical as well as the practical side.

### 3.1. Analysis, Modelling and Simulation

A location model is much more then a set of geographic coordinates, they can only contribute as a method to uniquely identify locations. Each location usually has a role such as representing a position in a specific street, being the entrance to a building or a meeting room. In indoor positioning any location can be defined by more then its coordinates as room, floor and building, giving a complete address, or relative positions within the room. The semantic of location information depends on the application domain.

The synergetic positioning approach processes a vast amount of data. For the algorithms in fusion and decision, for the continuity and the timeliness of the arriving data, appropriate models are being designed and evaluated in a mathematical analysis, and tested in simulations, before they are finally be implemented.

The modelling also needs to determine how other context classes can contribute to the improvement of positioning.

### 3.2. Testbeds and Experiments

As part of the NOMAD project [4], a wide scale infrastructure to support mobile applications is being deployed on the WIT campus. It includes Wifi positioning technology that is both software and hardware based. Each access point in this network is being polled for the list of devices currently associated to it. This gives device sightings for general campus areas. At certain spots of interest, the more accurate hardware based Wifi triangulation provides higher precision.

Based on a existing partnership with mobile GSM/GPRS operator O2 in Ireland, sub-cell location data can be obtained for an area of the city including the campus. Given the nearly complete penetration of GSM/GPRS handsets among the student body, a significant amount of data contributes to the system.

RFID reader technology is being installed at numerous points around the campus, tags are being dispensed in a large number (to handsets of participating students, to office property, to teaching material, etc.).

Visual tracking cameras are being deployed in selected labs only for current privacy concerns.

A dual Magnetic Swipe and Smart Card card of the WIT campus is currently being used for access control, library check-out and petty cash card. The debiting is processed in a central database, which will deliver data about the specific cash terminal positioning. The patch-panel database where fixed private IP addresses are assigned to room locations is being used for login-based positioning at workstations.

Exploiting all sources discussed above will provide the critical mass of redundant data to test the system architecture as described, and experiment with the data flow, while more theoretical aspects of the approach are being investigated.

## 4. References


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