Redundancy vs. Imperfect Positioning for Context-dependent Services

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ABSTRACT

Positioning, as a key component of context, has been a driving factor in the development of ubiquitous computing applications throughout the past two decades. However, the precision is limited to specific applications, the availability limited to the provider of specific services. Combining multiple methods allows 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. Location information can be inferred from infrastructure deployed for different purposes, only partly designed for positioning in the first place. The redundant heterogeneity of completely different recognition principles allows to tailor the perceived positioning probability to the specific requirements of the target application.

Keywords

Positioning, Quality of Context, Context Imperfection

INTRODUCTION

Location Awareness in general describes applications in computing and telecommunication, which alter their behaviour in dependence of the location of an entity. The latter might be the user of the application, a person the user of the application wants to communicate with, or an object capable of changing location. Such location represents a major category of *context* [5], and is derived by various methods of *positioning*.

Authentication is an issue implicitly related to certain methods of positioning, employing the same technology.

To achieve tradeability of contextual information among different organisational domains, it requires qualitative parameters regarding precision, trustworthiness and timeliness, recently phrased as *Quality of Context* [1].

A novel architecture massively *combines* multiple individual positioning technologies to obtain more precise and more reliable results according to the various needs of the whole range of location based services.

With Ubiquitous Computing thriving recently, dozens of applications demand such location information. It has sufficiently been discussed, that localisation indoors has different technological and topological requirements than outdoors. Even if we could derive a probable positioning of one meter, e.g. if we were able to receive GPS even indoors, this left us uncertain if we were at the one or the other side of the wall between two rooms. Thus, a different approach is required in local environments.

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

Progress in the latter issues is expected in most recent proposals to combine heterogeneous positioning data from different technological sources, in order to obtain a higher probability for a certain position scan by principles of data fusion [3][4]. The number of different parameters overlapping into a final position assessment is still small.

However, 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 be available 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. This means in an example, that for setting some room or music preferences in a smart environment, a recognition probability in the upper 80 percents would be sufficient, while paying money from an ATM would require much higher confidence in the authentication.

Within this paper, the related work is discussed in the following section. Section 3 introduces the architecture for individual domains including potential input channels, their inter-domain communication, and the aspects of security and privacy. Section 4 describes the ongoing implementation and section 5 concludes the paper.

RELATED WORK

Research into positioning systems has focused around leveraging location information from various media such as sound, infrared, radio and vision. Each system has addressed the aggregation of sensor data in to location estimations via their own specific methods.

This section presents a brief collection of related localisation technology which is not meant to provide an exhaustive analysis, but merely examples in order to discuss the pros and cons of each approach, and in particular to categorise them in regards of their current economical impact.

Widespread commercial systems

The list of widely deployed positioning services with everyday visibility is very short:

Radar for locating ships and aircrafts; the Global Positioning System (GPS) [8], as receptive radio localisation; contactless inductive transponder based positioning and visual on-the-fly bar-code recognition as widely used in factory hall logistics processes in industry. Cell based GSM location is explicitly used for its primary purpose of enabling communication.

Location inference

Another class of possible positioning are technologies not primarily developed for this purpose, but bearing implicit information which can be derived by inference of proximity.

Examples are readers (at fixed positions) for magnetic swipe cards or chip cards, used for access control and time registration, for money-related functions (credit cards), or combined functionality in a certain area (campus cards).

Further, network addresses (IP, MAC) can be mapped to positions (on a global scale already used for country or city-wise localisation of services like advertising or local language versions of websites). BlueTooth devices can be recognised in proximity to each other.

Laboratories and niche markets

Lots of positioning technologies have been developed in the labs, and to some extent commercialised for a number of niche markets.

Passive *RFID transponders* becoming cheaper, expected in particular from the AutoID initiative of the Automatic Identification and Data Collection industry [22], significantly driven by global consumer product manufacturers and retailers targeting to individually serial-number any item in the supply-chain with the Electronic Product Code (EPC) [23].

Sub-cell GSM positioning [24] – as an example for transmissive radio localisation and as demanded in the "E-911 mandate" [25] and similar European requirements – is currently too immature.

Indoors room-level positioning, requiring a different kind of granularity than geographical coordinates outdoor, lead to a number of approaches exploiting *Infrared* [9][10], *Ultrasonic* sound [7][15], and local-range *Radio Frequency* (RF). *Ultra-wideband* radio technology [11][12] becomes a promising technology in this area.

Weight or force measuring on the floor is another laboratory approach. It starts with the ORL Active Floor [13] and Georgia Tech's Smart Floor [18] – still requiring expensive installations. Currently, semiconductor manufacturer Infineon prototypes, in cooperation with the Vorwerk Teppichwerke carpet plant in Hameln, Germany, a "smart carpet", within their "intelligent textile materials" programme [19].

The *visual* channel is the most developed one for human orientation - and most challenging for technology. *Visual localisation and tracking* based on advanced stereoscopic image processing is a very promising approach [16], [20]. Falling costs for small cameras and increasing processing power make it feasible that such systems might take the place in the ceiling corners of the room, where nowadays the motion sensors of the burglar alarm reside. Privacy issues are of course most debatable within this area.

Concluding this section, none of the developments alone as discussed above would fulfil requirements such as affordability and precision targeted to specific applications. To provide a solution for a situation where the number of localisation areas (office/meeting rooms, multiple PoIs in exhibitions, campus) has the same magnitude than the number of persons or objects to be localised, further approaches have to be considered.

REDUNDANT 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, leading to different degrees of imperfection:

- Uncertainties in the actual position are mostly discussed in the literature, they are caused by the limited precision of the respective measurement, and can vary within the same technology, depending on the actual Dilution of Precision (DoP), e.g. depending on satellite constellations, RF multipath reflections, etc..
- Expectations of how long an object is still in proximity after a position scan might be based on typical assumptions. On a footpath, the typically expected speed would be pedestrian; or a location scan at the cash register of the cafeteria would assume a typical eating time of 20...30 min. But as exceptions, objects can be faster, and the lunch could have been interrupted.

- Relations between objects change, incidentally or intentionally. Labels fall off, the RFID tagged sweatshirt – so far a typical characterisation of a certain person – has been handed to the sister, or the cash card has been borrowed from a colleague to buy some coffee in the canteen.

If we compare these issues with ordinary human life, then we recognise people by a large number of individual characteristics. Facial properties, size, typical glasses worn, the style of clothing, voice, and many more. Even if one of these properties does not match, we recognise due to the redundancy of the other, compensating misleading information, and we adjust in a learning process some properties to new values, e.g. the new hair cut or other clothing.

Applying this behaviour to a technical system leads to the proposed approach of *redundant positioning* with a large amount of sensing nodes contributing to the whole image, including the consideration of imperfect, misleading and wrong information from individual nodes, and the accumulation of history data from previous sightings for the learning process.

Synergy and Redundancy

There is a large number of positioning systems and methods available. Each system has established characteristics including the overhead involved in installing its infrastructure support (hardware and/or software) and expense to procure the system. Extensive physical installation or high costs may limit large scale deployment to key areas. Other systems, such as those based on Wifi, may be easily deployed on large scale, but are limited in accuracy, and may be able to locate a sub-set of devices only. When multiple possible source of location data are pooled, greater coverage of an area can be achieved. As well as coverage issues, multiple sightings from different location systems can be used to reinforce or discount a user's estimation.

Temporal Validity

It can be argued that every sighting has a temporal validity attached to it. For example a device sighted by a WiFi location system will be valid for a small period of time (1 or 2 seconds). A user sighted using his debit card to buy a cup of coffee from a till in a coffee shop could be valid for a number of minutes (the time taken to drink the coffee). By attaching temporal validity data to a sighting the system can maintain location estimations between sparse sightings.

Confidence

The confidence is a measure of the potential error in a location estimation. It is not just a distance measuring error – it could also be an error in the perceived carrier of a located device. In other words, it is geometrical precision vs. detecting the wrong person. Confidence is important as applications potentially using the location information may reject it if the confidence is not high enough. As there are different classes of confidence (or errors, as discussed above), giving an application just a numeric value of confidence, e.g. in percent, is be sufficient when the type of possible error is relevant.

Input channels

Listing a number of possible channels below provides examples in the context of redundancy, not completeness. Naturally, different combinations of such channels will be exploited at different locations. Modularity is the key issue in this part of the architecture.

GPS

The satellite based positioning is embedded in an increasing number of devices such as PDAs and phones. It provides an interesting relevance for indoor positioning when the sudden absence of a GPS signal coincides with the last reception at the entrance of a building – this a valuable piece of information triggering the transition from the outdoor model into indoors.

RFID

Readers for RFID in gate situations like doors detect objects and persons passing, RFID readers in container objects (desks, briefcases, bags) detect their content, RFID readers at furniture and desk top inventory detect proximity of people and associated objects.

Visual tracking

Cameras in corners of the room track recognised contours (which are then personalised, if not by the visual technology itself, by mapping to reading RFIDs at specific points).

Floors

Weight-measuring floors, or the more economical Infineon carpet, qualify the trajectory observed by other positioning.

Wireless sensor networks (WSN)

Measuring proximity of people (e.g. temperature) by wireless sensor networks might be used alternatively to the floors. Alternatively, RFID readers might get so small and inexpensive that they can be deployed as self-organizing WSN.

Active Badges

The badges are an option for places where the obtrusiveness of these devices counts as positive argument (e.g. factory visitors), and the maintenance cycles can be fulfilled.

Biometric sensors

Providing a high (certainly not absolute) level of confidence, biometrics can be used punctually, when positioning requires that level of authentication.

Ultrasonic and Ultra-Wideband positioning

As long as the installation cost per room can be kept reasonable, the precision obtained from this principle can be helpful in calibrating other channels in the redundancy approach.

Wifi positioning

Using additional hardware provides more precision, but already the software-based approach alone is of major relevance for the redundant positioning approach, given the rapidly increasing installation base and coverage of wireless LAN. Already the cellular nature of an installation (supported by some more sophisticated approaches) provides good coarse positioning, well suitable to be complemented by other technologies.

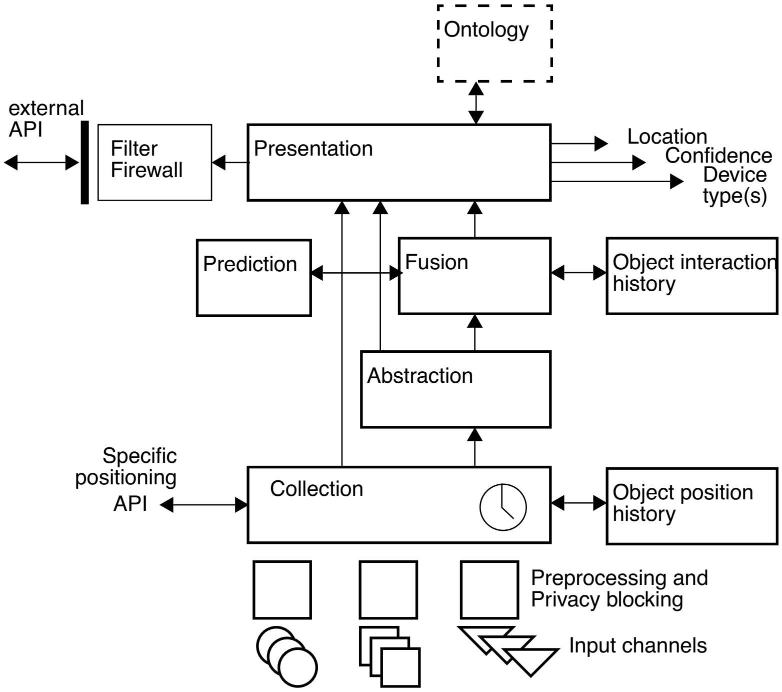

Figure 1: Architecture for redundant positioning

GSM and beyond

Cell and sub-cell positioning is an inherent feature of mobile communication, however the large business models behind the competing telecoms demand for exclusive exploitation of value-added location based services. This makes a cooperative approach difficult and requires a change of thinking.

Location inference

All software approaches based on already existing systems might be considered as location inference. Typically, these methods depend on the cooperation of the owner/operator of the specific system. Typical examples are recognising devices at wired ethernet patches, the proximity of Bluetooth enabled devices, the Wifi positioning already discussed, and the usage of swipe or smart cards at stationary stations. While usage at bank ATMs should be withheld for security reasons, a more relaxed policy might be acceptable for multi-purpose campus cards (library, access control, petty cash).

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

Architecture

In Figure 1, an architecture for the approach of redundant positioning is presented. 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, outputting the counting of same or similar scans. 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. So I might switch a video tracking camera in a mode prohibiting face recognition or apply temporal restraints. RFID readers could contain a blacklist of items not to be scanned (or, more restrictively, a positive list of allowed items, like office property). The Wifi positioning software might respect non-sighting escape zones, e.g. the canteen.

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. Its most important task is to provide a “plug-in” socket for each input channel.

Scans will be *time stamped* here, if they have not been stamped in their originating positioning system. This time stamp 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. Prediction is a supplement to fusion.

The *presentation* level must provide everything an application could possibly need. In coding location based services it is often equally important to locate a device as well as the person using it. Previously proposed approaches of fusion 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 he regularly wears. 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, has to be investigated.

For any external access, a *filter and firewall* module restrict access to an allowed amount of information, which can be adjustable to the degree of authentication the querying party provides. Further details about security and privacy are discussed at the end of this section.

Inter-Domain communication

It is logical to split geographic regions up for the purposes of ease of management, for example local government or councils. The same logic applies to location information systems. By making a location information system responsible for a specific area it limits the number of devices it has to constantly locate, thus reducing the stress on the system. Other location information systems can then be established to cover other geographic locations, or other property domains. If the systems are aware of each other and can query device locations from one another, a peer to peer location information network forms, as shown in Figure 1. Thereby, they operate as a group of "loosely coupled cooperating domains".

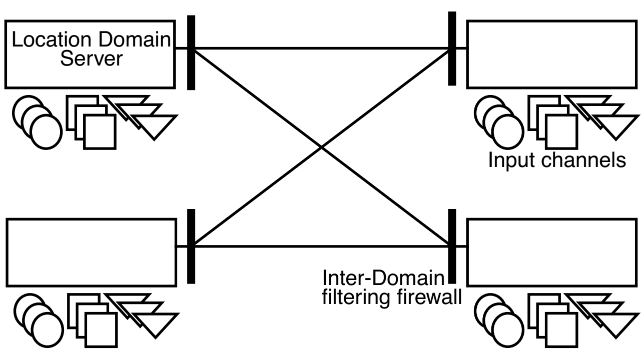

Figure 1: Inter-Domain location information exchange.

As the communication might comprise different administrative domains, different degrees of private or public services have to be considered. Therefore, a filtering firewall allows to tailor the data to the authorisation level of the other party.

Security and privacy

Security issues arise in particular when location information is exchanged between independent location domains. Privacy and ethical implications have become a topic of hot discussions [2] with few solutions so far. Location information firewalling and filtering, as well as early avoidance of collecting certain data are used to solve these issues.

IMPLEMENTATION

The previous section has described principles of redundant fusion for positioning and authentication in location aware systems. This approach is being followed from the theoretical as well as the practical side.

Data Model

A location is much more then a set of geographic coordinates. Coordinates can only contribute as a method to uniquely identify locations [27]. 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.

Testbeds and Experiments

As part of the NOMAD project [28], a wide scale infrastructure to support mobile applications is being deployed on the WIT campus. This infrastructure includes Wifi positioning technology that is both software and hardware based. So far it has been used for psychological experiments of group interaction among mobile device users, equipped with augmented PDAs.

Each access point in this network is being polled for the list of devices currently associated to it. This gives very general device sightings for general areas within the campus. At certain spots of interest, the more accurate hardware based Wifi triangulation provides higher precision.

Based on a existing partnership with one particular mobile GSM/GPRS operator 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, RFID 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 used as positioning information.

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 implement and test the system architecture as described before, and preliminary experiment with the data flow, while more theoretical aspects of the approach are being investigated.

Analysis, Modelling and Simulation

The redundant 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 can finally be implemented. Some approaches of handling the data stream can also been derived from the Auto-ID consortium, e.g. the Savant software [22].

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

CONCLUSIONS

Analysing technology for positioning available commercially and in the laboratories from a usability perspective, an architecture has been designed that allows to combine an arbitrary number of dedicated positioning systems and location inference methods to contribute in a synergetic and redundant way. This allows the reliable determination of positions of objects and persons, 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.

The presented architecture has purposely been restricted to positioning (including aspects of recognition and authentication), as a subclass of context. To what extent the interaction with the other subclasses of context would increase the usability of the system has to be investigated.

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