Harmonization of Position Providers

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***Abstract*—Hybrid positioning systems have been proposed in order to overcome the limitations of individual location sensing technologies. However, the large differences between the various technologies make integration into a larger system a challenge. This paper proposes a harmonization model which provides different location information sources with a uniform interface. The model creates an abstract representation based on performance criteria and our aim is to provide a basis for the design of location based services.**

The benefit of our approach is an extensible system that allows for seamless incorporation of new technologies. In addition, it offers a standard format for geographical positions, facilitating higher level treatment of information. To illustrate the usability of the model we implemented a prototype, the Global Positioning Module, which combines several commonly used technologies.

Keywords: positioning; harmonization; location-based service;

I. Introduction

The field of indoor positioning has gained interest due to the increased availability of mobile devices capable of location sensing. Whereas GPS has become the dominant technology for outdoor localization, there is still no equivalent dominant technology for indoor usage. There are several reasons for this. First of all, a relatively high accuracy is usually required inside buildings. As a minimum, room-level positioning must be possible, although a higher accuracy is often desired. For instance, a location based advertising system would need to know the customers' precise locations inside a shop in order to provide them with adds that are relevant to nearby products. This makes the methods typically used outdoor, such as satellite based technologies and cellular networks, unsuitable. Secondly, the high complexity of indoor environments causes distorted magnetic fields and severe multipath effects. The dynamism resulting from the usage of the indoor area – such as people coming and going, doors being opened and closed, furniture being moved etc. – only adds to this complexity, and renders the use of radio frequency technologies such as WLAN more difficult. As an example, the trilateration method becomes inaccurate because of the noisy signals and the fingerprint technique is vulnerable to changes in the environment.

These are some of the main challenges in the development of truly ubiquitous positioning systems. Such systems should be able to provide position information in all kinds of environments, indoor as well as outdoor. We believe that hybrid systems are currently the most promising approach. A multitude of indoor techniques exist but they usually require specific infrastructure, which limits their range and increases their deployment cost, e.g. the Active Bat system [1] and general RFID based systems. Infrastructure independent systems, such as sensor based dead reckoning, tend to suffer from drift because of the inherent inaccuracies of the sensors measurements [2]. Over time this causes their accuracy to decrease considerably and render them too inaccurate for indoor positioning. Hybrid systems try to overcome these challenges by combining several technologies into one single positioning system. This has several benefits, including increased accuracy and availability. For such systems to be feasible in practice they must be deployed on devices with suitable hardware, i.e. they must have a range of built-in sensors. Mobile devices such as smart phones and tablets fit this criterion. They are becoming more and more widespread in the general population, making them a good option for this type of systems.

Although hybrid systems have several advantages over those based on a single technology, their implementation is not straight forward. There are several issues that must be taken into account. Most importantly, the various technologies are generally incompatible with each other. Their position estimates come in all sorts of formats, ranging from absolute geographical coordinates to descriptive locations within a local frame of reference, such as "kitchen", "stairs" etc. Some of them only provide partial location data such as the altimeter and the compass. The way in which they are configured also varies considerably. While certain techniques require little or no pre-existing knowledge about the environment, such as triangulation or dead reckoning, others require lengthy and time-consuming surveys in order to function, e.g. the fingerprinting technique.

To integrate the technologies into a common system they must be harmonized in some way. By harmonization we mean the application of a standard by which all sensing technologies can be represented. This representation serves as an interface by which an overlaying framework obtains location information in a defined format. It ensures that the framework is technology-independent and extensible since the technology-dependent details are hidden by the harmonization process. We consider these two properties to be fundamental to the creation of a universal positioning system.

In this paper we propose a model for harmonizing position providers, a term used to denote any component, hardware or software, that is capable of location sensing. Our work is motivated by the current lack of standards in the field of positioning and our aim is to provide developers with a model that serves as a basis for the architectural design. Our model is based on the assumption that any positioning technology can be represented by a common set of criteria. The natural way of evaluating a system is by its performance and we have therefore chosen criteria that define the expected quality of the position provider's output. This representation serves as a common position provider interface, and at the same time gives us a mechanism for selecting technologies based on their performance.

The remaining sections of this paper are organized as follows. Section II provides an overview of work related to hybrid positioning frameworks. In sections III, the position provider model is presented together with a detailed description of the criteria and the position estimation format. Section IV describes an actual implementation of the model, and our conclusions are summarized in section V.

II. Related Work

In an attempt to standardize an ever increasing amount of positioning technologies, several frameworks and models have been proposed. Early work in this area includes the Location Stack [3], which provides a multi-layered abstraction for location-aware ubiquitous systems, and its implementation [4], in the form of a flexible framework that successfully integrated three different positioning technologies.

A technology and application independent framework was proposed in [5]. The authors describe a five-layered context model used for processing low level sensor output into high level locations and present an implementation based on a distributed server-client architecture. They state that a generic location handling framework has four requirements, namely a layered context model, a distributed architecture, a technology independent and extensible location format and a technology independent programming interface.

Kritzler and Krügler [6] present four challenges related to tracking using data from heterogeneous sensor sources. They addressed the challenges by developing geTrack, a tracking system capable of using input from different sensors on a device. A data model for the storage of the sensor output data is proposed. Two use cases in which their system is used are presented, for each of them they employed different data analysis methods.

iPOS [7] is another multi-technology positioning architecture, developed specifically for mobile devices with limited resources and off-the-shelf sensor hardware. It has a plug-in architecture, allowing for easy integration of sensor plugins, making it robust and scalable.

A recent effort is the distributed indoor location system able to combine multiple technologies proposed by Martínes, Villanueva, Santofímia and López [8]. Their solution consists of two sub-systems, a Location Event Provider and a Location Event Consumer, separated using an object oriented middleware. A high level interface is defined to provide users of their service with a unique way of handling position information.

Few studies have touched upon the subject of position provider harmonization. Eric Dorveaux and Nicolas Petit [9] harmonized two subsystems, an attitude sensor and a velocimeter. The two sub-systems are attached to a rigid body. They identified a rotation matrix, or *harmonization* matrix, between the two systems' frames of reference, and used it to compensate for drift.

The novelty of our work is a model created to harmonize technologies that are normally incompatible in terms of configuration, usage and output data. The previous work concerns global design models for the whole location based system, or focuses on a particular set of technologies. What we propose is a solution specifically aimed at solving the issues related to integrating multiple positioning technologies into one single framework and rendering the communication between the technologies and the rest of the framework independent of technological differences.

III. A Harmonization Model

Conceptually, position providers constitute the lowest layer of a location based service. They transform raw sensor data to higher level position estimates and make them available for further processing. Additionally, they serve as an interface to the higher layers of the service, giving them a standard way of accessing location information from different sources. The model has been developed with the aim of providing what we consider to be the most important properties of a universal positioning system, namely technology independence and extensibility. Technology independence refers to the ability of the system to use any location sensing technology without having to make special adaptions. In other words, a change of technology should be transparent and not require re-configuration or modifications of the system. By extensibility we mean that new sensing technologies can be integrated into the framework or service without requiring modifications to higher layers. This feature allows the system to be adapted to any kind of environment, since the developer may easily add whichever technology is necessary in order to satisfy the requirements of the system. This feature is important because the preferred location sensing technology is likely to change depending on where the system is used. As an example, consider a busy airport where a Wi-Fi positioning system is available versus an unpopulated area where GPS is the only option. For the system to be considered universal, it must offer the developer the possibility to include any technology that is relevant for the system's area of usage.

A taxonomy outlining the different parameters by which location-sensing systems varies is offered in [10]. We present those parameters that are relevant to our work and show how the proposed model handles the various cases:

- *Physical position versus symbolic location*. Some systems will provide specific geographical coordinates, e.g. the GPS which defines locations using latitude, longitude and altitude. Others provide symbolic locations, representing positions using abstract descriptions. As physical positions can usually be augmented to symbolic locations, our model defines only physical positions in order to stay as versatile as possible.

- *Absolute versus relative*. This property refers to the located objects' frame of reference. In an absolute system, they all share the same coordinate system, whereas in a relative system, they can each have their own reference frame. For the sake of consistency, the model requires that all positions are within an absolute frame of reference, using geographical coordinates.
- *Accuracy*. The average error of systems varies considerably. Some are able to provide centimeter-level accuracy while others have an accuracy of several kilometers. This property must be carefully evaluated against the requirements when choosing a positioning system. The model provides a mechanism for selecting the technology that is best suited for a given setting.
- *Scale*. This refers to the coverage area of a system, which is often limited by its infrastructure. The combination of multiple technologies, as our model promotes, is currently the most promising way of extending the coverage area.
- *Cost*. The cost of a positioning system depends on several factors, including the hardware, the installation procedure and the tracked mobile units. It is often desirable to avoid the installation of dedicated hardware due to its high cost, and rather reuse existing infrastructure. Since systems that apply our model are able to take advantage of a multitude of information sources, the cost could potentially be reduced.

The application of our harmonization model to a hybrid positioning framework yields several important benefits. First of all, it provides a standard, both for the representation of technologies and for the communication between provider and framework. The criteria based solution that we propose is the principal contribution of this paper. Second, it leads to low coupling between the various technologies and the rest of the system because the model ensures that each provider is treated as an independent, reusable component. Third, by creating so-called *combined providers*, i.e. providers that use the output of other, lower-level providers as their input, combination and fusion of position estimates is easy to achieve. This allows for the implementation of a wide range of algorithms, from simply combining the output of two providers to more complex fusion algorithms such as Kalman filers and particle filters.

In the following sections we present the details of the proposed model. At its center is the *position provider*, which is an abstract concept that represents a positioning technology. The positioning technologies that are available today are highly diverse, yet the only requirement in order for the model to be applicable is that it is able to produce complete or partial positioning information, and that the accuracy of the technology's output is known.

A. Criteria

The set of criteria is one of the main components of the position provider. The idea behind the criteria is to eliminate any individual differences between technologies and to create a way to easily evaluate the suitability of a provider using a given algorithm. As the model is intended to work with both 2D and 3D systems, some of the criteria are specified in both the horizontal and the vertical direction. The full list of criteria is as follows.

- *Horizontal accuracy*. The mean error between the real and the estimated position, measured in meters.
- *Horizontal precision.* Three discrete values from a cumulative probability function are used to represent the precision, namely 50, 80 and 95. A system that declares a precision of (10, 15, 30) has a location accuracy of 50% within 10 m, 80% within 15 m and 95% within 30 m.
- *Horizontal distance drift*. Distance drift of the system, measured in %. The drift is used for systems where the accuracy decreases with the distance, like for dead reckoning. For instance a drift of 20% means that the estimated position has an accuracy value augmented by 20 m after travelling for 100 m on a straight path. The drift value is measured like the accuracy (mean distance error).
- *Horizontal distance drift rate*. Time drift of the system, measured in meters per seconds. The drift is used for systems where the accuracy decreases with the time, even when there is no movement. An example of such a provider would be one based on inertial sensors.
- *Vertical accuracy*. Same as for horizontal accuracy but for the altitude.
- *Vertical precision*. Same as for horizontal precision but for the altitude.
- *Vertical distance drift*. Same as for horizontal distance drift but for the altitude.
- *Vertical distance drift rate*. Same as horizontal time drift but for the altitude.
- *Priority*. The provider's priority, 1 being the highest. The priority defines the default selection order in the cases where two or more providers are equally suited, or no criteria have been defined. If several position providers are able to return a position according to the user's request, then the one with the highest priority will be chosen. For instance, if the user only asks for a position, while not giving any preferences like the power consumption or the required precision, then the one with highest priority will be chosen.
- *Room detection*. The probability of detecting the correct room, on the correct floor, in percentage. A room is defined as an area within a building enclosed by walls, a floor and a ceiling and having at least one entry point. The doors and windows may be open or closed. For providers based on electromagnetic

radiation, their capability of room detection is influenced by the degree of signal attenuation caused by the construction materials of the building. The materials can be highly diverse, and include concrete, wood, glass and metal, all interacting differently with the signals. Providers capable of returning an exact location, such as barcodes, will have 100% correct room detection, provided that information about the geographical layout of the building is available. Techniques relying on fingerprinting should give the percentage measured when doors are open.

- *Power consumption standby*. The average power consumption in mAh of the provider when it is in stand-by mode, meaning ready to take a measure.
- *Power consumption request.* The average power consumption in mAh of the provider for each position request. The total power consumption of a provider is the result of power consumption standby + power consumption request * U / 3600, where U is the update rate in Herz (U = 0.1 means that a measure is done every 10 seconds).

As already mentioned, the criteria specify expected performance and output quality, and our aim is to provide a set that fully characterize all properties that are relevant to the provider selection procedure. These values are static and should not change during usage of the system. We have partially based our choice of criteria on the survey presented in [11], in which the authors state that accuracy and precision are the most important evaluation criteria of positioning systems. In addition to those related to the providers' output we define criteria that are important from an implementational point-of-view, namely those related to power consumption. To illustrate their usage, we could imagine a system running on a device with limited battery power. When the power-level reaches a critical threshold, the system would automatically change to a provider having a lower power consumption, even though this might decrease the accuracy of the position estimates.

In addition to the static criteria, the model also includes dynamic criteria. They describe properties that are likely to change regularly, and their values should be updated accordingly:

- *Refresh rate*. The rate by which the provider updates its current position. There are several reasons why it would be necessary to change the refresh rate, including power saving and increasing/decreasing the accuracy.
- *Availability*. The availability of the provider. Whether or not a provider is available depends on several factors. Most importantly, providers depending on external infrastructure will be unavailable when the user moves to an area where there is no such infrastructure. Also, service or infrastructure failure can render the provider unavailable. This criterion is therefore essential for the provider selection procedure to function correctly.

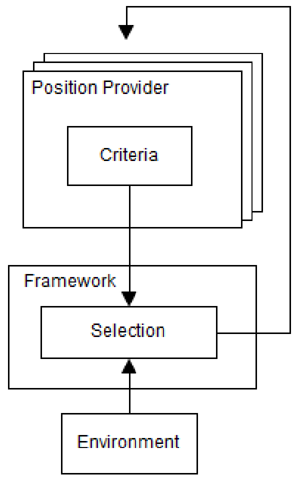

Figure 1. Selection of position providers.

In the case of a provider based on a third-party system, such as GPS, the values of the static criteria may be specified by the producer and be easy to obtain. Otherwise, a survey must be performed in order to obtain statistical data about the provider's performance, from which the criteria can be computed.

In the following, we briefly describe how the criteria are intended to be used together with the rules that define the position provider selection. The selection procedure is illustrated in figure 1. The rules are related to the surrounding environment and the system must therefore be aware of its context. As an example, we could imagine a situation where several positioning technologies are available in the same building, and where a particular area inside the building requires a higher accuracy that the rest. A suitable rule could be to always use the provider with the lowest power consumption, except in that particular area, where the provider with the highest accuracy is chosen. These rules are not directly part of our model and their implementation must be designed on a per-system basis.

In systems consisting of several information sources, it is common to perform some kind of data fusion. If fusing data is necessary, it should be done by creating combined providers. The combined provider itself would contain the fusion algorithm, and be responsible for managing the output from the sub-providers which it uses. Its output would be the result of the fusion algorithm. This has the benefit of keeping a clean design, since complex combinations of providers can be created without having to modify the provider selection procedure.

B. Position Estimate

The second important component of the model is the format of the provider's output, the *position estimate*. It is usually the result of a transformation process performed on raw measurement data. This means that it is the responsibility of each provider to make sure that its output is correctly formatted. Having a common output format for all providers is a key feature of a universal system as it saves the higher layers from having to deal with the particularities of any given technology.

The position estimates contains geographical information gathered by the provider, i.e. each measurement results in a position estimate. In order to accommodate a wide range of providers our proposed format contains all information that we consider necessary to completely describe an object's position. Certainly, most providers will not be able to produce all this information, the goal is rather to ensure that any piece of data may be used by the overlaying system. Even though a provider may only return partial information, a combination of the output of several such providers might yield a very accurate position estimate. As an example, consider the combination of GPS output with that of an altitude provider based on an altimeter. Generally, the altitude returned by the GPS is less accurate than the horizontal position. Therefore, a combination of the output would be more accurate than if GPS was used alone.

The position estimate consists of a geographical position, acceleration, orientation, speed, accuracy and a timestamp. Here, we present the format in details:

1) Position

The position is given in three dimensions using latitude, longitude and altitude. Latitude and longitude are defined using 7 decimal degrees, which gives each of them an accuracy of 1.11 cm at equator. As one moves away from equator, the distance represented by a longitude degree decreases due to the curvature of the Earth, leading to the longitude becoming more accurate the closer one is to the poles. The accuracy of the latitude remains the same independent of the distance to equator.

The altitude is defined as meters above sea level. Since there are areas that lie below sea level, the altitude may be a negative number.

The reason for using 7 decimal degrees is that we need to account for current and potential future positioning systems capable of offering centimeter-level precision. Examples of systems already capable of providing less than 10 cm accuracy are presented in [11] and include Active Bat, and the Beep system. A better accuracy (millimeter-level) has been deemed unnecessary for a system intended for human positioning.

2) Acceleration

The acceleration is defined as the rate of change in velocity over time, relative to free fall. In other words, it measures the force of translation in a given direction. It is measured in m/s^2, and the model supports acceleration in three dimensions in order to accommodate output from multi-axis accelerometers. Acceleration may be positive or negative, the latter indicating either that the speed is decreasing in the direction of movement or that speed is increasing in the opposite direction.

3) Orientation

This parameter describes a device's orientation with respect to the Earth's frame of reference, and is represented by the devices' rotation around three axes. The orientation must not be confused with the direction of movement, because the two are not necessarily the same. An example of this is when the mobile device is held with the screen tilted 90 degrees while the user is walking.

The orientation is measured in degrees, using the standard definitions of pitch, roll and azimuth.

- *Pitch.* Describes forward and backward tilting, or rotation around the x-axis. The pitch takes on a value in the interval]-180,180]. When the device is lying such that its z-axis points upwards, the pitch is zero. The pitch is positive when the device is turned such that the z-axis moves in a clock-wise direction until it points downwards, and the device has been turned over, going from 0 to 180. If the device is instead turned such that the z-axis moves in a counter-clock-wise direction until the device is completely turned over, the pitch goes from 0 to -180.
- *Roll.* The sideways tilting or rotation around the y-axis. The roll will have a value in the interval]-90,90] and is positive when the positive z-axis rotates in the direction towards the positive x-axis, and negative otherwise. This can be illustrated with the following example: A device lying such that its z-axis points upwards, has a roll of zero. If the device is flipped 90 degrees to the right, in the direction of the positive x-axis, the roll increases to 90. If the device is flipped further, the roll decreases until it again reaches 0 when the device has been turned 180 degrees. If the device is instead flipped in the other direction, the roll values will be negative.
- *Azimuth.* Represents sideways turning, and is the equivalent of the compass direction. In other words, it is the rotation around the z-axis. Azimuth is measured in degrees east of the geographical North Pole and its range is defined as [0,360[.

4) Speed

The speed is measured in m/s.

5) Accuracy

The accuracy of a position, measured in meters. We represent accuracy horizontally and vertically instead of using the x, y and z axis. The reason for this is that while there are systems, such as GPS, that have different accuracies in altitude versus latitude and longitude, we know of no systems that have defined differences in accuracy for the two horizontal dimensions, nor do we see it as likely that future systems will inhibit such properties.

6) Timestamp

The timestamp marks the point in time when the position was recorded. It is defined as the number milliseconds elapsed since January 1, 1970, 00:00:00 UTC.

C. Data gathering

The process of obtaining, transforming and distributing positioning information is described in the following and illustrated in figure 2. The provider's data transformation can conceptually be divided into three stages. The first is the actual data acquisition, where the provider receives raw data. Data is

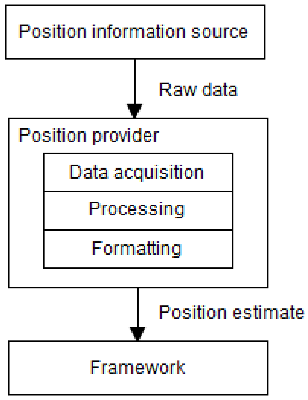

Figure 2. Transformation of raw output data to formatted position estimates.

generally acquired as the result of a scan for external units or from probing built-in sensors on the device. The type and format of the data varies considerably depending on its source. The second stage, the data processing, transforms the raw data to a geographical position. This often involves calculations on the raw data, as is the case with the triangulation and the fingerprinting methods. This stage may require external information. Again, the fingerprinting technique is a good example as it needs access to a radio map of the area. The laststage is the formatting of the data, in which the position estimate format defined above is applied. The implementation of these stages is entirely dependent on the underlying technology and will differ from provider to provider. The final position estimate is transferred to the higher layers, which are responsible for any further processing.

IV. Implementing the Model

In this section we present a framework based on the model, illustrating how such a system may be designed. The framework, called the Global Positioning Module (GPM), is in an early stage of development and exists in the form of a prototype, currently being tested in a research project at the University of Geneva related to navigation and guidance for elderly people. The framework runs on Android devices and makes use of their built-in sensors as well as several web-based services in order to estimate the location of the device.

Part of the framework's requirements was the ability to support both indoor and outdoor navigation and in particular positioning inside a typical home, as well as museums and airports. To fulfill this requirement, a wide range of self-positioning modules were implemented, based on the position provider concept. The providers include several of the most commonly used technologies, such as GPS, Bluetooth, WLAN, dead-reckoning and cell towers. In addition, combined providers have been implemented – most notably GPS combined with an altitude provider that uses several different web services to obtain a mean altitude for the horizontal coordinates.

The framework has a simple, modular architecture consisting of two main components – the kernel and the position providers. The latter groups together the aforementioned positioning modules. We defined a Java interface that specifies the operations that can be performed on a provider, basically the starting and stopping of the location sensing and methods for retrieving the current position estimate. This serves as the external application's access point to the framework. As each provider uses the same interface, changing positioning technology is easily to achieve. The kernel component is responsible for the creation, initialization and configuration of each provider, and contains the definitions of the frameworks interfaces.

Each provider contains its own set of criteria which is used in the implementation of high-level combined providers. While the low-level providers function on their own, the combination of several providers using a criteria based algorithm allows for a more flexible and accurate position estimation. The actual provider selection algorithms are still in design stage and will be included in later releases of the framework, which will allow us to evaluate the accuracy of the system. Currently, position estimates are obtained directly from the low level providers.

V. Conclusions and Future Work

In this paper we presented a model that harmonizes different types of positioning technologies with the purpose of creating a basis for universal hybrid positioning systems. Harmonization is a process in which we apply an abstraction on to the various technologies so that the overlying framework can communicate with them in a standard and technology-independent way. We defined a set of criteria that characterize the quality of the technologies' position estimates and provided a definition of a universal geographical position format. These are the foundation of the model which provides framework developers with a structure for creating their own algorithms for selecting the most appropriate technology for a given setting.

As an example of the application of the model we presented GPM, a framework developed by our research group and which applies the principles described in this paper. The framework has been integrated into one of our research project s as a low level source for positioning information and is currently being tested.

Future work includes further development and evaluation of the model. The testing of the framework in a real-world-situation will provide us with useful feedback with regards to refining and improving the model. We also intend to add new providers to the framework and to improve the existing ones in order to obtain better accuracies.

Acknowledgements

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