Journal of Network and Computer Applications 67 (2016) 75–85

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

Survey of challenges and towards a unified architecture for location systems

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ARTICLE INFO

Article history:
Received 24 August 2015
Received in revised form
25 January 2016
Accepted 17 February 2016
Available online 8 March 2016

Keywords:
Localization
Positioning
Survey
Challenges
Architecture

ABSTRACT

Localization is a key aspect of emergent applications in the medical, industrial and consumer field. In this article we survey state of the art, identify current challenges and issues for localization systems and suggest a unified layered architecture. The analysis reveals that challenges cannot be addressed in an isolated manner for example, energy consumption is tied to the choice of algorithm and employed hardware. To separate various challenges and investigate them independently, we propose the concept of position providers. Position providers in the lower layers allow abstraction of positioning methods, positioning algorithms and positioning hardware. Thereby, a position provider encapsulates methods, algorithms and hardware. Furthermore, we suggest a classification of position providers inspired by related work. We propose a unified architecture for location systems which uses positioning and integration layers as main building blocks.

1. Introduction

Location information is beneficial for medical, industrial and consumer applications. In the past, *location based services* (LBS) have been suggested. LBS enable *services*, e.g. friend finder, if the location of a user is known (Schiller and Voisard, 2004). However, the view has changed over the years in a way that both people and things should benefit from the knowledge of a location. The concept of location based services faces problems when applied to *smart objects* as envisioned by Kortuem et al. (2010). For example, for goods tracking in warehouses location information itself is a *service*. Such applications require *location services* instead of location based services. Another example are *Smart Things*, with built-in microelectronics and radio devices. Such smart things enable new applications for the *Smart industry* if parts or objects, e.g. in the automotive industry, have precise location information. Location services need to be integrated into systems, e.g. location based services or enterprise resource planning. This shows that location based services are not sufficient to deal with upcoming challenges.

Researchers from several areas of engineering successfully developed technologies for determining locations. However, researchers have a unique way to perceive and describe problems and solutions. This results in various definitions of terms which makes it difficult to retrieve an overview of current problems and challenges in the field of positioning systems.

As a first step, we use the following terminology and definitions for the rest of this article. An *anchor*, *reference node* or *reference object* serves as a reference for the positioning. An *object of interest* is a *tag*, *mobile equipment*, *user device* or *item of interest* which requires localization. A composition of anchors, object of interest and processing unit form a *positioning system*. Depending on the kind of positioning system, we distinguish between global positioning systems and local positioning systems. Local positioning targets a small scale, i.e. tens of meters, in contrast to a global positioning system which operates on a large scale i.e. hundred several kilometers or even worldwide. Furthermore, we distinguish between location and position. A *position* is a quantitative representation of an object attribute in a given coordinate system, whereas a *location* is a position enriched with additional information, e.g. context. This distinction follows the suggestion of Filjar et al. (2008) and provides a clear differentiation between positioning and location systems.

A positioning system is often part of a larger arrangement, for example a location based service or a geographic information system. In this article, we focus on the lower layers of the architecture, namely the positioning layer and middleware layer. Our contributions in this article are:

- Survey of available architectures for positioning and location systems.

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http://dx.doi.org/10.1016/j.jnca.2016.02.009
1084-8045/

- Survey of challenges of the lower layers of such systems.
- Survey of available localization systems and their technologies.
- Concept proposal of position providers to decouple positioning method, positioning algorithm and positioning hardware from each other.
- Discussion of an integration layer with multiple position providers to build hybrid location systems.

The rest of the article is structured as follows: Section 2 describes architectures for existing location systems and motivates a layered view towards the problem and we introduce the concept of position provider. In Section 3 we address challenges of location systems and show how those interrelate each other. We survey implementations of location systems in Section 4 and expand the concept of the position provider to isolate the challenges. We discuss current classifications and show limits of existing approaches to characterize positioning systems and provide a new classification for location systems based on position providers in Section 5. We provide a discussion of the integration layer with focus on service advertisement and handover between positioning systems in Section 6. Finally, a summary and an outlook to future work is presented in Section 7.

2. Architecture for location systems

In this section we discuss architectures for location systems. We start with a general overview of available architectures and discuss common features between location systems and develop a unified architecture.

2.1. Survey of available architectures for location systems

A stacked architecture was proposed by Greßmann et al. (2010). In the proposed architecture of Greßmann, a *positioning layer* is connected to a hardware layer which manages sensors and other hardware. On top of the positioning layer, there are the correction layer, the location API and the addressing layer. The correction layer corrects faulty or imprecise positions, whereas the location API provides functions for location awareness. The addressing layer is responsible for communication between mobile entities. On top of this architecture is the *application layer* where the location aware application resides in.

A more detailed discussion of a location stack was presented by Hightower et al. (2002). The stack from Hightower et al. features seven layers for ubiquitous computing systems. Hightower et al. considers different sensor technologies (distances, proximity) for the sensor layer. The output of the sensor layer is raw data from sensors. The next layer, the measurement layer, transcribes raw data into useful data, e.g. distances or angles, whereas the following layer (fusion layer) performs sensor fusion and provides relative location information. The arrangement layer transforms relative location information into a single location. Context fusion layer, as the next layer, fuses the single location information with personal data, e.g. calendars or email. A sixth layer, a machine learning system, categorizes the context information and location aware activities. The last layer, the intention layer, relates this information to the user.

Gu et al. (2009) discussed a basic approach of a location aware architecture in his survey paper. The architecture features three layers: location based application layer, a software location abstraction layer and a location sensing layer. The application layer processes location information via an API. Software abstraction layer converts data from the location sensing layer to the application layer and serves as a *middleware layer*. The location sensing layer provides position and location estimation. Similar approaches have been suggested by other researchers, for example Schiller and Voisard (2004).

An implementation of an architecture is shown by Chakroun et al. (2010) where the authors propose a localization architecture for pervasive environments called LocSys. The LocSys architecture features a detection, decision as well as a refinement and presentation layer. Each layer is composed of different sub-layers with more specific tasks. For instance, the detection layer utilizes a sensing layer to observe its surroundings and provides information of available access points/wireless technologies. Adoption sub-layer and processing sub-layer calculate positions based on available data. The last layer, decision and refinement layer, performs coordinate translation into global coordinates and provides API's to the presentation layer.

2.2. Unified architecture for location systems

Location systems were incorporated into a number of several systems, e.g. robot localization (Rodas et al., 2013; Lategahn et al., 2010), consumer applications (Newman, 2014), IEEE 802.11 positioning (Mazuelas et al., 2009), time based systems (Shen et al., 2010) and many more. However, all location systems share common concepts and tasks. In the previous section we have seen that each location system requires some kind of signal detection/measurement of a location depending parameter (Laaraiedh et al., 2011; Gu et al., 2009; Hightower et al., 2002). In a unified model it is important that a wide range of technologies are supported, even multiple technologies simultaneously cf. Hightower et al. (2002) and Greßmann et al. (2010). Such technologies are incorporated into a complex system which we define as *position provider*. The position provider provides an abstraction for the middleware layer. The tasks and components of the position provider are developed in the course of this article. The positioning layer manages multiple position providers and provides service access points to upper layers where integration takes place, which was also suggested by Greßmann et al. (2010). Each position provider manages one positioning technology. The middleware layer is responsible for integration of the multiple position providers, e.g. for data and context fusion. Furthermore, the middleware layer converts the location information into a format the application understands. Fig. 1 shows the unified architecture based on the positioning and integration layer. Finally, the application layer processes the location information. Typically the location system is a part of a larger entity, e.g. a location based service or an Enterprise Resource Planing system which offers service based on the location of an object of interest.

In the next section we survey the challenges of the three layers and investigate available location systems to find common problems and similarities.

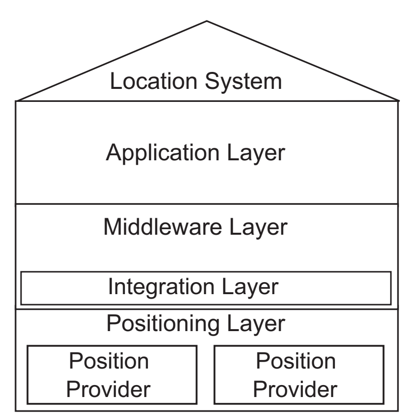

Fig. 1. Proposed unified architecture of a location system.