From Heterogeneous Sensor Sources to Location-Based Information

Tracking and support of service technicians in an industrial environment

Mareike Kritzler
Institute for Geoinformatics
University of Münster
Münster, Germany
kritzler@uni-muenster.de

Andreas Müller
Advanced Technologies and Standards
Siemens AG, Industry Sector
Nürnberg, Germany
Andreas_w.Mueller@siemens.com

***Abstract*—This paper describes the transformation process from spatio-temporal coordinates to location-based support. This transformation is described as a workflow starting with heterogeneous sensor sources, which provide spatio-temporal data. As a next step, data fusion operations provide a precise and accurate location. This location is subsequently enriched with context information. The main contribution is to establish a dynamic link between the spatio-temporal aspects of a smart industrial indoor environment and its descriptive semantic information model in order to enable location-based support of service technicians with mobile devices.**

***Keywords - Tracking, Sensors, LBS, Georeferencing*.**

I. Introduction

Smart indoor environments are used in multi-disciplinary research areas and different contexts like Smart Homes, Classrooms or Industrial Environments. They are equipped with different technologies, sensors and actors. The purpose of Smart Environments is to support human beings in their daily life in real time [1].

A. Problem

Smart environments are equipped with different sensor sources. Location and tracking technologies collect spatio-temporal data in the form of three-dimensional coordinates. Single sensor sources are not precise and accurate enough but the combination of various technologies and different levels of instrumentation allows an exact indoor positioning. In this context three major problems arise:

- Without the fusion of all obtained spatio-temporal data, the exact spatial position of tracked items cannot be determined. The resulting Cartesian coordinates describe a position at a certain timestamp based on a known reference system in the environment.
- Without the enrichment of fused positions with context information, we would lack information about the current spatial context, which is required for different subsequent tasks.
- Without the deployment of applications (to support users) for mobile devices, the context coordinate cannot be used to obtain location-based information in a smart environment.

B. Motivation

To provide location-based support for human beings in a Smart Environment, the transformation from fused spatio-temporal coordinates to context information can deliver necessary location-based information. A workflow from coordinates to information is needed to be applicable to Smart Environments in different contexts. Location-based information is necessary in all kinds of applications.

For example, smart industrial work environments require service technicians to be constantly provided with correct instructions for performing various maintenance tasks. Service technicians use mobile devices for in-situ context-sensitive information provision. Especially in dynamic environments the applicability of work instructions is strongly dependent on the technician's spatial position. However, location-based information can only be provided if individual positions are known exactly. The consideration of the associated contexts allows to close the gap towards a semantically meaningful processing.

The presented work is motivated by the need for spatial support for service technicians in an industrial environment to efficiently and safely accomplish their maintenance work.

C. Background

Information required by service technicians is always dependent on prior phases in the plant lifecycle (see Figure 1).

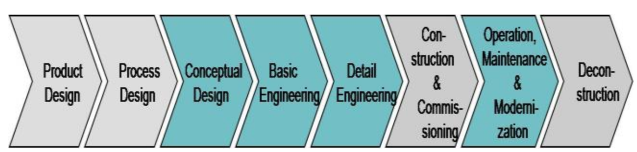

Figure 1. Plant lifecycle (adapted from [10])

During the phases *Conceptual Design*, *Basic Engineering*, and *Detail Engineering*, plant drafts, designs, and documentation of the plant are created. These are essential information sources for maintenance tasks. Among others, these include topological, structural and functional information, stored in different formats such as visual representations, e.g., 3D computer-aided design (CAD)

 ISBN: 978-1-61208-100-7

models or floor plans, or text-based semantic information models. Thus, spatial knowledge is created and used for the respective plant prior to the *Operation, Maintenance and Modernization* phase. However, each phase relies on individual specialized information representations, resulting in a heterogeneous information landscape. Product/Plant Lifecycle Management (PLM) systems attempt to cope with this heterogeneity by employing a more unified information model over the entire plant lifecycle, making task-specific information available for all phases on request. Still, when performing maintenance tasks, a service technician needs to use floor plans, maps or other navigational means in order to reach and identify a component to be serviced and to subsequently access the related information from a PLM system. By connecting these capabilities and information warehouses with localization and spatio-temporal information processing, service support systems can benefit from unified access to all necessary PLM information based on the technician's current position, thus being transformed into location-based services (LBS) for maintenance tasks.

The proposed problems were addressed in a joint project that took place in cooperation between the Institute for Geoinformatics and the Siemens AG. At the Siemens location in Nürnberg Moorenbrunn an industrial research facility, called the *Smart Automation Center* (SmA), is operated (see Figure 2). The SmA, which is equipped with different kinds of sensors, serves as a lab environment for the development of various conceptions and technologies in the field of manufacturing automation. There, among others, conceptions for multi-modal support of service technicians are developed.

Figure 2. Picture of the SmartAutomation Center in Nürnberg Moorenbrunn

D. Outline

Section II gives a short description of further smart environments. In section III the setup of the smart environment with the sensors and use cases is shown. Section IV describes the architecture and the components, which are used to get from heterogeneous sensor sources to location-based information. In the last section V the paper is concluded and an outlook is provided.

II. Related work

Smart Environments are developed and established for various purposes and with different contexts. Homes become smart with intelligent surfaces, wall displays or by monitoring the movement of their inhabitants [2]. This paper focuses on the smart industrial environment available at the Siemens laboratory. In the following, further examples for smart research laboratories are listed:

A. SmartFactory [3]

The SmartFactory is a manufacturer-independent European demonstration factory for industrial applications of modern information technologies. The factory aims at the development of innovative technologies for industrial plants. Furthermore, applications for different industrial branches are developed. The work done in the SmartFactory is divided into five parts:

- Localization services
- Virtual factory
- Control systems
- Mobile devices
- Basic technologies

B. Living Lab Innovative Retail Laboratory [4] (IRL)

The IRL is a research laboratory, which focuses on topics related to intelligent shopping support systems. The assistance systems are tested concerning their suitability for daily use. Different forms of interactions with consumers like speaking products as well as intelligent shopping carts are developed. Furthermore, indoor positioning and navigation are part of the research.

C. Bremen Ambient Assisted Living Lab [5] (BAALL)

BAALL is a 60 m² big apartment, which is invisibly equipped with different technologies. The apartment is disability-friendly and in accordance with the requirements of elderly people. The idea behind the project is that elderly persons can stay as long as possible in their own apartments, which are able to assist and support the inhabitants when they need help. Focus lies on the mobility assistance and on environmental support. For mobility assistance, an intelligent walker has been developed [6]. Furthermore, a controller for an automatic wheelchair was developed for smart driver assistance [7].

The interoperability and standardization of the inbuilt components are an important requirement for the development of assistance systems.

III. Setup

The SmA allows the addressing of different challenges along the plant lifecycle. In the following the purpose of the SmA, the applied technologies and a use case, which is taking place in the SmA are described.

 ISBN: 978-1-61208-100-7

A. Smart Automation Center

With its different functional modules, the SmA realizes a complete exemplary product lifecycle by filling, inspecting, commissioning, and recycling bottles with various products. For the entire plant, highly detailed 3D CAD models are available (see Figure 3), as well as PLM information models for selected components.

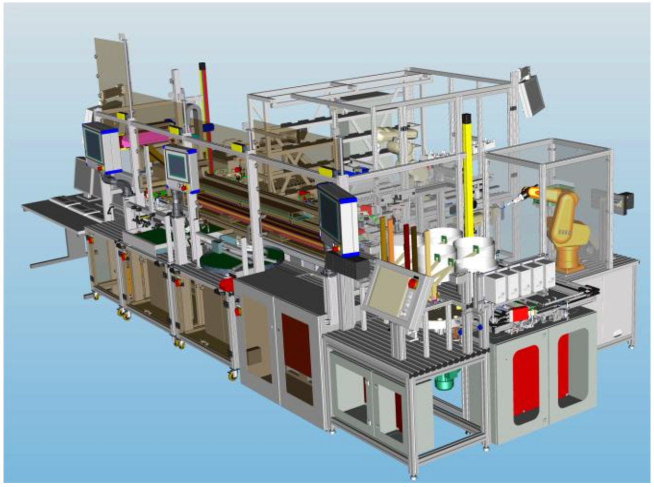

Figure 3. 3D CAD model of the SmA

Among other activities, ideas for the improvement of multi-modal support for service technicians are developed in the SmA. These include ideas how to:

- obtain proper / correct instructions, so-called task flows, in dynamic working environments
- efficiently place and use digital notes on components as a means of collaboration support
- obtain necessary component-related information, dynamically adapted to individual situational needs.

The SmA is equipped with various kinds of sensors, which are discussed in the next section.

B. Tracking and localization technologies in the SmA

Different tracking and localization technologies are integrated in the SmA to obtain spatio-temporal data (see Figure 4). In this scenario, Ultra Wide Band (UWB) (Ubisense) and RFID technology are in use. Installed keystroke sensors, which have a fixed location are also used for location determination. Additionally, localization via Wireless Local Area Network (WiFi) Fingerprinting is possible as well.

- UWB: This generic term characterizes radio systems with huge bandwidths [8]. The Ubisense [9] system (Series 700), which uses UWB radio signals, is established for multi-user tracking in the SmA. The mobile location tags transmit UWB radio signals to four receivers installed in the SmA. This allows three-dimensional indoor localization. Empirical experiments in the SmA show a precision of approx. 20 cm on the horizontal plane and approx. 30 cm along the vertical axis. Unfortunately, in some areas of the SmA, positioning is strongly impaired because of shielding due to metallic materials (like in the high rack storage).
- RFID: The RFID system, which is in use in the SmA is installed as a terminal approach. This means that the positions of the RFID readers are dynamic while the positions of the RFID tags remain static. The RFID readers are attached to mobile devices and change their locations in time with the user. The RFID tags are placed in the SmA at different components and have fixed positions (a three-dimensional coordinate). The position has to be taken a priori and stored in a database. The timestamp of the reading event together with the identifier of the RFID-reader are used for tracking.
- Keystroke sensors: All mechanical sensors, which can be used by human beings are summed up as keystroke sensors, e.g., the emergency stop button, the control panel of the bottle picker or the touch panels, which control components of the SmA. All of these sensors have a fixed position. Furthermore, their usage can be logged. The position has to be taken a priori and stored in a database. The keystroke sensors can be used as a source for precise positioning in the SmA because the exact location is known as well as the time stamp when it was in use. However, the localization is anonymous and in a multi-user scenario the coordinates can only be assigned to a single user if other tracking and localization technologies are in use at the same time.

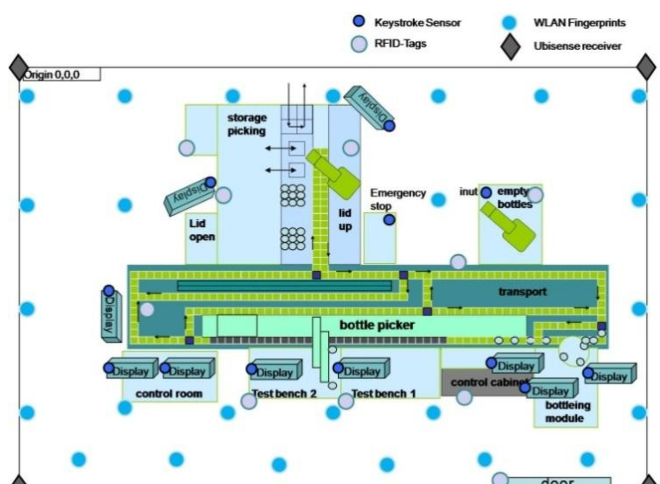

Figure 4. Schematic overhead shot map of the SmA with integrated sensor sources for location determination

- WiFi: Data collection via WiFi fingerprinting uses the received signal strength (RSS) of access points, which are installed in the building hosting the SmA. The fingerprints have to be taken a priori with a mobile device for the whole SmA. The precision of the localization depends on the amount of taken fingerprints. Furthermore, the strength of WiFi signals is variable and can lead to imprecision.

C. Use cases

Service technicians are supposed to have in-situ access to all required information and directly use all required information on both the maintenance task to be accomplished and the component to be serviced. Hence, several fundamental use cases have to be considered in terms of such mobile support for service technicians (see Figure 5).

Although the SmA serves as a relatively small lab environment, the use cases considered here are equally valid for full-size industrial plants and other smart environments.

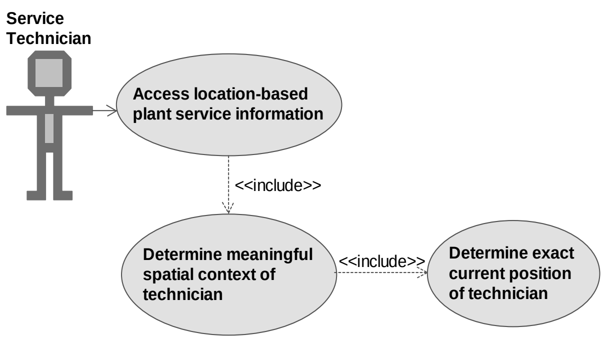

Figure 5. Main use cases considered in the scenario displayed in UML notation

Firstly, the technician's exact current spatial position needs to be determined. However, not all localization technologies are equally well-suited for an entire plant. Instead there are different areas within the plant where some localization technologies typically show better performance than others. For instance, high rack storage areas might block UWB localization. In such cases, making plant components directly identifiable by equipping them with e.g., RFID tags would be useful. However, this would result in high effort for the plant operator, especially when carried out after plant construction. From this point of view, different localization technologies have to be considered in a combined approach in order to compute the actual current position.

Afterwards, the semantically meaningful spatial context of the technician's position has to be determined. This is necessary because of the nature of issues in the field of service support. For instance, service technicians might need to ask for the components that a specific to-be-serviced component in front of them is connected with, e.g., electrically ("Which components are powered by this power supply?") or even in terms of the entire production process ("What are the effects of shutting down this conveyor belt?"). The service phase is part of the plant lifecycle. In this context usually semantic models are employed for the representation and management of this type of service-related plant or component information. Such semantic models are the basis of PLM systems. However, due to their origin, these models typically do not rely on spatial information but instead use unique names (URIs) for the identification of the described components and their relations. If at all, spatial information is merely provided as an optional attribute and thus cannot be used as identification criteria. Furthermore, the required domain logic for handling spatial issues is typically not part of PLM systems or other semantic information management systems. Therefore a contextual link between the purely spatial world and the world of semantic plant information management has to be introduced.

Finally, the determined contextual meaning of the position needs to be used for location-based access to service-related information. Since the service technician moves within a semantically described plant, his movements and position in the vicinity of components can be used to provide him with location-based information from a plant information management system.

IV. Architecture

This work consists of three different parts. First, the spatio-temporal data has to be collected and fused. Second, the Cartesian coordinates have to be enriched with context information. Third, the coordinate has to be used as an input for applications on the mobile device (see Figure 6).

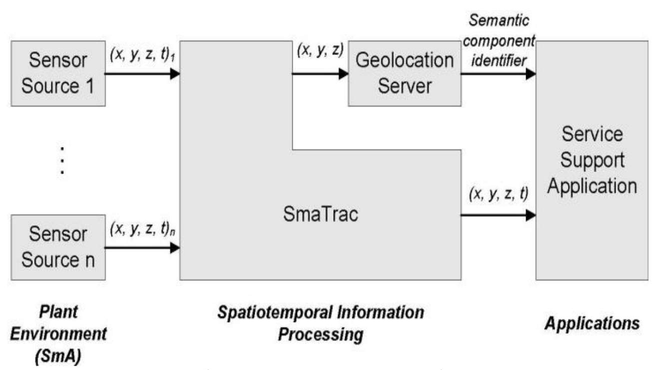

Figure 6. Flow of the Cartesian coordinates for mobile support

A. SmaTrac – Handling of tracking data

Smart Environments are equipped with different kinds of sensor sources. The SmaTrac framework was developed to integrate and process spatio-temporal data obtained by heterogeneous sensor sources from moving items (e.g., like service technicians). This framework, which was implemented in Java does not rely on, nor is it limited to, one tracking or positioning technology but instead considers the combination of several technologies to calculate the best positioning result. SmaTrac is scale-independent (in space and in time) and considers different sizes and characteristics of the tracked items as well as different tracking environments or contexts. The framework consists of four parts:

- Data collection:
  The framework has to be able to use data obtained by heterogeneous sensor sources and has to provide common storage for the data.
  The implementation provides a universal data schema for a relational database. This schema is able to store both data, which has to be taken a priori and spatio-temporal data, which is taken in real time. The data scheme stores localization events, which consist of timestamps and IDs for the sensor sources. The sensor source ID is the key to the coordinates. Furthermore, the schema allows the storage of metadata concerning the tracking or localization technologies, which is important for further processing.
- Data processing:
  The processing has to enable the combination of data obtained from different technologies.
  The spatio-temporal data is processed in a core component. The core is able to use different sensor fusion approaches, but in the first implementation the position is calculated by the arithmetic mean. For more advanced fusion approaches, the precision and accuracy are taken into account when new coordinates are calculated from coordinates, which were obtained by different sensor sources.
- Data providing:
  The framework has to be able to fetch data out of a relational database as well as to provide it to external applications.
  The framework provides different internal and external interfaces. Internal interfaces enable the retrieval of stored data from the database and provide the fused data to different applications. External interfaces are used to provide the processed data (the output of the framework) to external applications as their data input. The data is provided in Extensible Markup Language (XML) format to make the reuse of the processed data with already implemented software possible.
- Data usage:
  The framework needs to use calculated coordinates for further domain-specific applications.
  One application, which can be used for different contexts and tracked items is the visualization application. The use of Java 3D and the Virtual Reality Modeling Language (VRML) makes the display of all kinds of three-dimensional context models of different environments possible.
  Other applications analyze large amounts of data, for example via machine learning techniques, to find patterns of tracked items.

B. Geolocation Server – Giving tracking data a meaning

Most tracking or localization technologies use a coordinate-based approach to provide locations. Available indoor localization and tracking systems offer coordinates in a predefined reference system. SmaTrac uses and calculates Cartesian coordinates. Cartesian coordinates describe locations by a set of numerical values. Positions are determined sufficiently by that approach but the circumjacent context is neither described nor known. The Geolocation Server overcomes this lack of contextual awareness. It introduces a service layer, which enriches Cartesian coordinates with context information. The usage of well-known standards allows its introduction into any service chain, and therefore the enhancement of traditional tracking with context-based information. The Geolocation Server is mainly divided into two functional parts:

- Data processing:
  Context information has to be assigned to specific coordinates (by annotation of coordinates with object references of their surrounding context) to realize a LBS, which provides context information.
  In this implementation, the Geolocation Server uses a Web Feature Service (WFS) and Filter Encoding (FE). Existing CAD files (see Figure 3) were converted into 2.5D shapefiles (these are models of the environment) and annotated with Unique Resource Identifiers (URI) pointing toward additional information stored in ontologies. The usage of FE permits to query for a set of coordinates. The retrieved context of the coordinate is transmitted, encoded in the Geographic Markup Language (GML) and serves the URI along with the geometry of nearby objects.
- Data providing:
  The identified entities of the circumjacent context of the coordinates have to be communicated via a machine readable interface. The interface has to provide the logical entities' geometry and a set of attributes, which can be used to obtain further information like electrical or mechanical connections.
  The implementation uses the URIs to gain additional needed information of any kind. This approach allows one to use this LBS – the Geolocation Server – as a machine-readable middleware layer for other applications assisting users at their task.
  It is possible to obtain information about the surroundings of the coordinates by blending existing blueprints and floor plans with the tracked coordinates in a common reference system. Annotations in the blueprints point toward additional resources, which can hold functional descriptions or topological information.

C. Application – Providing location-based information

On this level, a variety of applications are possible. This could include the display of electrical or mechanical connections of a component, the provision of maintenance

ISBN: 978-1-61208-100-7

instructions, the adaptive display of floor maps, or the handling of digital notes attached to components.

Two different applications have been created:

- The SCADA system SIMATIC WinCC [11], which is installed in the SmA for plant control, represents plant areas and components by means of operable image elements. This control system was extended by an ontology describing structural and functional aspects of SmA components. Subsequently, the image elements were enriched by mappings to features identifiable by the Geolocation Server and to individuals in the ontology. In this scenario, the service technician can learn about the exact location of a specific SmA component and its vicinity along with its structural and functional aspects by selecting the corresponding image element onscreen. By using extensions of WinCC for mobile devices and transferring the respective images, it is also possible to e.g., highlight certain image elements on the mobile devices according to the technician's current position.
- As part of the German Federal Ministry for Research and Education (BMBF)-funded project AVILUS [12], semantic enhancements of digital graffiti – so-called "Virtual Post-It" – have been researched. By means of Virtual Post-It, service technicians can attach semantic descriptions of the actions performed during service tasks directly to plant components. These Virtual Post-Its can subsequently be used by the technicians for collaboration purposes as well as for dynamic adaptation of location-based service information situationally supplied by PLM systems. Here, the setup provides essential localization information, since both the technician's position and the locations of affected components need to be determined constantly.

V. Conclusion and Outlook

This paper describes the architecture of a dynamic link between different sensor sources and a location-based application in the case of indoor tracking of service technicians in an industrial smart environment. Cartesian three-dimensional coordinates obtained by heterogeneous sensor sources are first fused to get the best (that means the precise and accurate position) indoor location. The new coordinate is then used in a georeferencing process to gain access to location-based and context-related information, which is provided by a mobile device.

The main contribution of this work is the architecture of a transformer from Cartesian coordinates to location-based information. The architecture is independent of both the used localization and tracking technologies and the smart environment. Thus, semantic information models describing a smart environment become accessible on grounds of a user's spatial position.

In addition to it, this paper shows the results of a productive cooperation between theoretical university research and industrial application, which are in use in industry.

In future, the development of Virtual Post-It will continue. Furthermore, extending the setup with prediction of specific tasks and likely maintenance workflows is being considered.

Acknowledgment

We thank the members of the Siemens AG, Industry Sector, Advanced Technologies and Standards for their support and we thank the AVILUS team for providing us with data. We also thank Antonio Krüger for his research advising.

References

[1] P. Mikulecký, T. Lišková, P. Cech, and V. Bureš. "Book Series on Ambient Intelligence and Smart Environments". Published by IOS Press. Volume 1: Ambient Intelligence Perspectives. 2009.

[2] A. S. Taylor, R. Harper, L. Swan, S. Izadi, A. Sellen, and M. Perry. "Homes that make us smart". Journal Personal and Ubiquitous Computing, Springer, London, Volume 11, Number 5, pp 383-393, June, 2007.

[3] Homepage of SmartFactory: http://www.smartfactory-kl.de/. Date of access: 2010-05-23

[4] Homepage of IRL: http://www.dfki.de/web/living-labs-de/irl. Date of access: 2010-05-23

[5] Homepage of BAALL: http://baall.informatik.uni-bremen.de/en/index.php/Main_Page. Date of access: 2010-05-23

[6] T. Röfer, T. Laue, and B. Gersdorf. "iWalker - An Intelligent Walker providing Services for the Elderly". In Technically Assisted Rehabilitation 2009.

[7] T. Röfer, C. Mandel, and T. Laue. "Controlling an Automated Wheelchair via Joystick/Head-Joystick Supported by Smart Driving Assistance". In Proceedings of the 2009 IEEE 11th International Conference on Rehabilitation Robotics, pp. 743–748, 2009.

[8] K. Siwiak. "Ultra-wide band radio: introducing a new technology". Vehicular Technology Conference, 2001. VTC 2001 Spring. IEEE VTS 53rd. Vol 2. Pp 1088-1093.

[9] Homepage of Ubisense System: http://www.ubisense.net/en/products. Date of access: 2010-05-23

[10] VDI-Richtlinie 4499 Blatt 2: "Digitale Fabrik – Digitaler Fabrikbetrieb". December 2009.

[11] Homepage of WinCC SCADA: http://www.automation.siemens.com/mcms/human-machine-interface/de/visualisierungssoftware/scada-wincc/Seiten/Default.aspx. Date of access: 2010-05-23

[12] Homepage of AVILUS: http://www.avilus.de. Date of access: 2010-05-23

 ISBN: 978-1-61208-100-7