Enable Location-based Services with a Tracking Framework

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Abstract. In order to obtain information and knowledge about moving entities, spatio-temporal data needs to be collected and analyzed. The idea is to establish a generic tracking framework that is able to integrate, combine, process and analyze spatio-temporal data that is obtained from heterogeneous data sources. This framework allows for the establishment of new location-based services for different scenarios in various domains.

Keywords: Location-based service, spatio-temporal data, data fusion, data analysis

1 Introduction

The knowledge of movement and behavior patterns of moving entities such as humans, animals and objects is important in marketing, industrial engineering and behavioral biology, for example. In order to gain this knowledge, spatio-temporal data, which contains implicit information about the movement and behavioral patterns of tracked entities, has to be gathered and analyzed. Tracking systems (such as the Cricket system [3] or the project RADAR [1] for example), which incorporate different localization technologies and methods, gather spatio-temporal data from moving entities. The number and diversity of tracking systems has rapidly increased in recent years. A single system does often not suit scenario's requirements, such as accuracy and precision, or has physical limitations. Thus, the combination of more than one system is necessary for data collection. The lack of uniformity for tracking systems and insufficiently applied analysis methods call for a more general approach for spatio-temporal data integration and analysis in order to gain information about or for tracked entities.

2 Problems

Different challenges exist regarding the tracking of moving entities and information gaining from spatio-temporal data. Depending upon tracked entities, tracking environments and scenarios, many heterogeneous tracking systems are simultaneously in use in order to gather spatio-temporal data. This leads to a variety of data sources as well as a huge amount of spatio-temporal data which has to be processed and analyzed in order to gain information or knowledge.

P1. An overall approach does not exist to integrate and process spatio-temporal data obtained by different data sources.
  – An architecture needs to be developed to integrate different spatio-temporal data.
  – Methods have to be established for the processing of spatio-temporal data from different data sources.

P2. A general approach to propose a reusable solution is missing for more than a single problem in a certain scenario.
  – A scale-invariant modeling of the environment and of the scenarios have to be created.
  – A reusable concept for data processing and a generic approach for modeling different scenarios have to be developed.

P3. A standardized format to combine spatio-temporal data with different properties is missing.
  – A standardized data schema for a common data management has to be designed.
  – A fusion of all gathered spatio-temporal data has to be considered for a continuous localization result.

P4. A set of reusable methods to analyze this data is missing, thus very little information is previously able to be obtained.
  – Different top-down analysis methods need to be developed to obtain information out of the processed spatio-temporal data.
  – Different bottom-up analysis methods need to be developed to obtain information out of the processed spatio-temporal data.

3 Motivation and Idea

The motivation is to find solutions to the four problems mentioned above and to support humans in their daily routines based upon collected spatio-temporal data.

The overall idea is to be able to replace multiple applications that are only in use for one certain scenario in a particular domain. This application should result in a homogeneous data set that allows the user to gain information about tracked entities.

Thus, the idea is to establish an interdisciplinary scientific tool that allows for the integration and combination of spatio-temporal data obtained from heterogeneous tracking systems in scenarios of different domains. The tracking data can be continuous or non-continuous and accurate or inaccurate. The idea is to provide a data schema that allows for the integration of non-continuous and accurate with continuous and inaccurate data: Different tracking systems have different properties. For example, proxy sensors (such as touch screens or keyboards, for example) deliver 100% accurate positions because they have fixed coordinates and a tracked entity has to be at that location in order to trigger a sensor; on the other hand, this data is not continuous in space because of the spare distribution of proxy sensors. A tracking system based upon radio-waves produces continuous data but the data obtained with ratio-waves underlies variations in the accuracy. This non-continuous proxy sensor data could be combined with continuous radio-wave data to fill the gaps between the proxy sensors. If data of two or more partially inaccurate tracking systems is available for the same time point, the combination of this data can also lead to a more precise and more accurate tracking result than the data from only one sensor.

4 Goals and Contribution

The goal is the development and establishment of a generic, scale-invariant in space and time, data fusion and analysis model for collected spatio-temporal data. The resulting tracking framework addresses the four problems listed above. Furthermore, the information obtained from different kinds of moving entities is independent of size and environment.

The goals for the proposed tracking framework include the integration, storing, processing and analyzing of spatio-temporal data. The focus is not to develop new systems to collect data nor the provision of drivers for existing technologies but to integrate and combine data from existing systems.

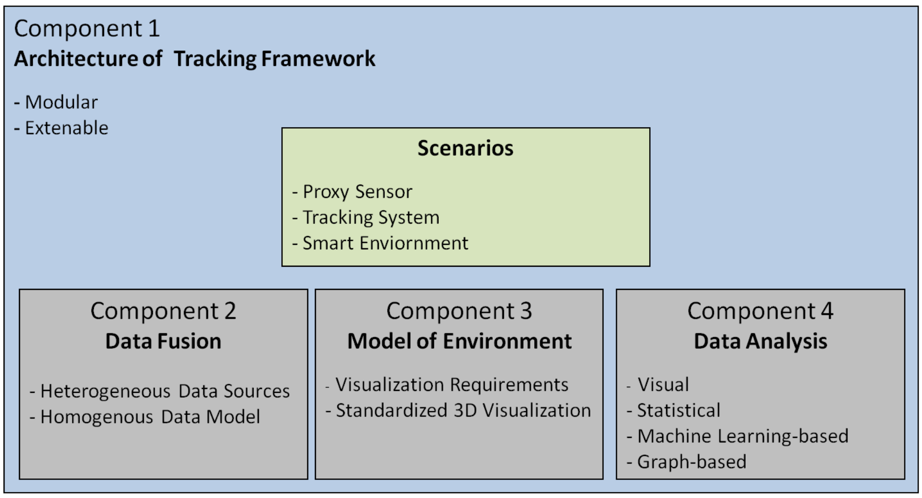

Fig. 1. The four components of the tracking framework

The contribution of the proposed tracking framework is to provide a general approach to integrate and to analyze the spatio-temporal data obtained by various tracking systems with visualization, statistics, machine learning methods and graph-based analysis to generate a benefit to the domain experts. The tracking framework is divided into four different components and incorporates three differently equipped scenarios to show the generic and extensible approach (see figure 1).

Furthermore, the data can be processed together and used in different analysis modules - depending upon the level of instrumentation in the tracking environment - to obtain information (see figure 2). The framework can be applied to tracking tasks in different domains. Different domains contain various levels of instrumentation, starting with a low instrumentation consisting of proxy sensors up to smart environments with a dense instrumentation through different tracking systems. Integrated and processed data leads to knowledge about tracking entities in the available analysis modules.

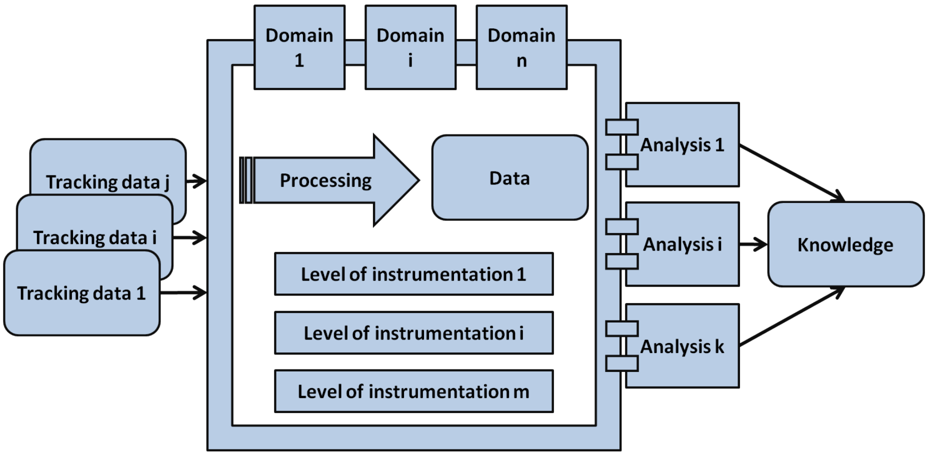

Fig. 2. The idea of a scientific tool that is able to process data in different analysis modules.

In the case that the user is not the entity to be located, experimental scientists (such as biologists) could be supported in their daily work by allowing them to collect and process large quantities of moving entity data. Important information and knowledge about movement and behavior patterns of animals, for example, could be obtained from the processed data.

If the user of the framework is the same as the tracked entity, tracked people (such as service technicians) could get assistance while following their daily workflows by taking their location into consideration. Further information about the tracking environment or their tasks, for example, could be provided based upon the current coordinates.

5 Tracking Framework

The generic tracking framework is able to integrate, process and analyze spatio-temporal data which is obtained from heterogeneous data sources. This framework considers combinations of several tracking systems as well as the integration of data from proxy sensors, such as touch screens, with a fixed location in an environment. Furthermore, the analysis of moving entities is scale-independent with regard to spatial and temporal resolution. The framework allows for new location-based services which provide an additional benefit to their users based upon spatio-temporal movement and behavior.

The framework addresses the problems of missing uniformity and insufficiently provided methods. Integration and processing of spatio-temporal data obtained by different tracking systems is enabled with the provision of a homogeneous data schema for spatio-temporal data and metadata. The data schema specifies units for measurement and time. The framework is implemented modular in order to allow for further extensions and uses a relational database management system for data storage.

For the fusion the following cases have to be considered: If more than one measurement for the same time is available by different tracking systems, the fusion of one or more coordinates has to be done. In the case that one data entry has already 100% confidence, the coordinate of this entry is used for the particular point in time. Alternatively, if both entries have less than 100% confidence, the data is fused by using a weighted mean of the values. The weight can be determined with different approaches such as with a simple motion model which is proposed by [2].

In order to allow for the analysis of spatio-temporal data, bottom-up and top-down analysis methods are provided. Machine learning methods are provided in order to find movement and behavior patterns in large data sets in a group of tracked entities. If the focus is on investigation of differences between different tracked groups, statistical analysis is used. In the case that non-continuous localization data is available, but a continuous track should be reconstructed, tracks are simulated with a graph-based approach. Furthermore, a graph matching approach is provided, which matches existing patterns in obtained data for the detection of existing movement and behavior patterns. Finally, to assist with visual analysis of one or more tracked entities in their environment, the display of a three-dimensional environmental model with the display of the movement of tracked entities based upon the collected data is available in the framework (see figure 3).

The framework has limitations that are not part of the research which are briefly listed in the following. The framework does not integrate sensor sources, only their data. Furthermore, it does not provide drivers for the integration of technologies. Only Cartesian coordinates are considered in the data model. The analysis of real-time tracking data is not part of the current version of the tracking framework. The framework neither provides methods for visual modelling nor considers any privacy issues.

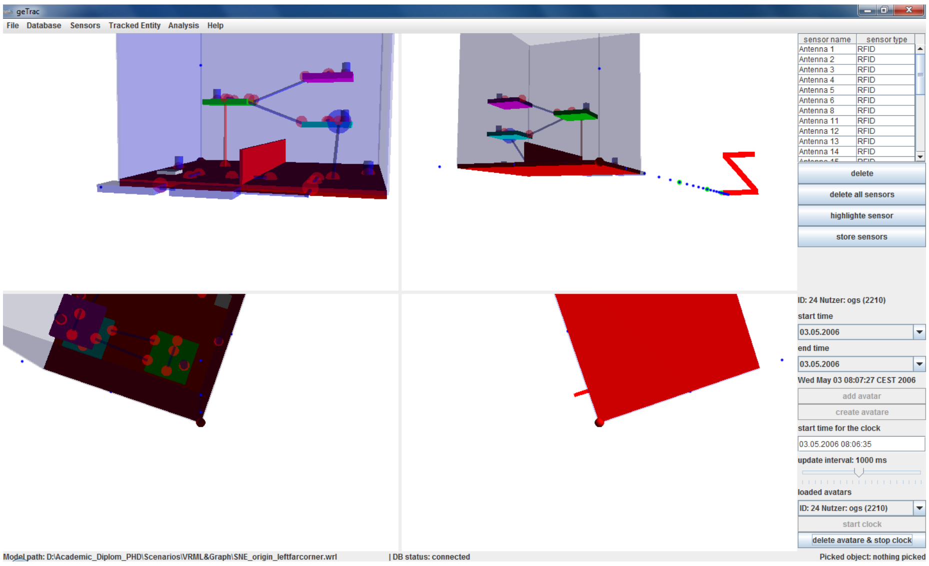

Fig. 3. Screenshot of the tracking framework prototype

5.1 Scenarios

Different sizes and characteristics of moving entities are considered as well as different tracking environments. Data is gathered with proxy sensors that are available in the tracking environment. In this case the framework demonstrates the ability to obtain track information from anonymous discrete movement data which lacks temporal information. Graphed-based simulations illustrate paths that could have been taken by moving entities under the assumption of different movement and behavior patterns. Data is also obtained from a certain tracking system. Then, visual, statistical, machine learning-based and graph-matching analysis are in use to gather information and obtain knowledge about movement and behavior patterns. The use of computational methods allows for the finding of more patterns in the data. Furthermore, data is collected in smart environments (such as the SmartFactory[1] or the Innovative Retail Laboratory[2], for example) which uses many different tracking systems. A data schema for a common management of the data allows for the combination of the different technologies. A visualization of the multi-target tracking provides spatial support in a smart environment.

In order to emphasize the generic approach of the tracking framework, three distinct scenarios in different domains are used to develop and apply the tracking

[1] SmartFactory. *SmartFactory*. Available from: http://www.smartfactory-kl.de/ (Accessed April 4, 2011).

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framework. Real world scenarios for the tracking framework include the tracking of: department store customers, laboratory mice and service technicians.

6 Conclusion

In order to integrate, combine, process and analyze spatio-temporal data a generic tracking framework for moving entities is proposed which is scale-independent with regard to spatial and temporal resolution. It provides an additional benefit to its users based upon spatio-temporal movement and behavior as it allows for the establishment of location-based services. This framework analyzes spatio-temporal data which is obtained from heterogeneous data sources. Furthermore, this framework does not rely upon one tracking and localization system for the data collection, but instead considers the combination of several systems as well as the integration of proxy sensors, such as touch screens, with a fixed location in an environment. The established tracking framework incorporates spatial locations and allows for reactive and device-oriented location-based services. This framework can be applied to all kinds of collected spatio-temporal data, and standardized interfaces make it possible to reuse it with different mobile systems which contributes to the filed of mobile computing.

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