Model based activity recognition in smart home environments

Jens Ellenberg, Bastian Karstaedt, Kai von Luck, Birgit Wendholt
Hamburg University of Applied Sciences, Hamburg, Germany

***Abstract*—In the area of *smart homes* context aware systems play a key role towards adaptive smart environments. Our research currently focuses on the combination of positioning information with model-based approaches to recognize residents activity patterns (e.g. "breakfast routine"), in order to adjust the environment accordingly (e.g. light, sound and temperature). We employ a semantically enriched IFC building model for spatial analysis tasks and an ontology based component to reason about typical activity patterns in order to derive reliable situation estimations. *Living Place Hamburg*, a fully functional smart home, allows for evaluation of our results under real life conditions.**

***Keywords*—smart home, context awareness, low level context reasoning, spatial analysis, ontology based context reasoning**

I. Introduction

Our smart home, the *Living Place Hamburg* [1], is a 140sqm loft style urban apartment. It consists of one large room with different sections for dining, living, working etc. as well as a separated bathroom. It's a complete functional apartment and therefore suitable for experiments under real life conditions. All sensors (e.g. location, temperature, capacitive, cameras) as well as light and sound effects are freely configurable allowing settings to be influenced in many ways. Currently we have developed and installed software and hardware to remote control the window and heating system as well as an indoor location system[1]. We are working on a range of lighting scenes suitable for typical situations.

Based on the following scenario, where we introduce "Mary" our resident, we will further elaborate our approach presenting the models and procedures involved in order to come up with a reasonable guess about situations and a control setting for a reactive environment in turn:

Mary is getting up early in the morning. She is moving towards the bathroom in order to take a shower. Afterwards she is dressing in the bedroom and has breakfast in the kitchen area. Finally she leaves her home and is going to work.

In order to create a stimulating environment for these morning rituals - in our terms activity patterns - e.g. "getting up", "washing", "dressing up", etc., we first need to recognize these patterns. We will then be able to map patterns to control settings for the light, window or heating system.

In our approach we try to combine low level semantic interpretation of basic activities like trajectories of movements at a specific day of a week, daytime and weather conditions (e.g. moving from A to B at a weekday in the morning at a cold winterday) with spatial knowledge based on an IFC model (e.g. the movement observed started at the bedroom area, ended in the kitchen area), and ontology based reasoning (e.g. this movement belongs to a weekday morning ritual).

[1]The location system under use is Ubisense based on ultra-wideband technology with high centimeter range precision.

II. Interpretation layers

In [2] we presented our overall architecture and the principles of the activity pattern recognition. The architecture is divided into different interpretation layers. The intermediate layer yields knowledge about spatial entities, their relations and the residents whereabouts. This knowledge is used on a higher level where a model of typical domain tasks and situations supported by an activity ontology will detect (and react to) behavioral patterns of residents. The two layers are described in the following with back references to the scenario introduced before.

A. The Indoor Spatial Information Service

A 3D model of our smart home (cf. Fig. 1) has been constructed with Autodesk® Revit Architecture. The resulting IFC file serves as an input for the *Indoor Spatial Information Service* (ISIS) introduced in [3]. ISIS combines spatial information in the IFC building model (e.g. spatial relations and attributions of rooms and furniture) with external location information in order to create intermediate level semantic interpretations.

By now ISIS has three major tasks:

1) providing continuous spatial information about the residents' whereabouts
2) providing a spatial service for requests by use of 3D spatial relations
3) keeping the digital model consistent with the environment

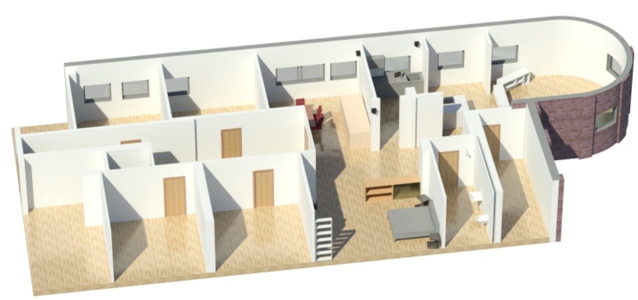

Fig. 1. A rendered view of the living place IFC building model

The 1st task deals with the questions: where *was*, *is* and *will* the resident be? Based on the spatial information in the IFC model ISIS constantly informs other subscribers about changes in the spatial context by means of a blackboard message server. ISIS hereby offers higher level spatial information like path descriptions as trajectories between rooms and the residents' abidance with respect to a functional space. A person situated inside a functional space of an object is likely to interact with this object (e.g. when Mary is inside the functional space of her wardrobe for a while in the morning, she is likely to dress up). The building model also gives us the opportunity to predict a resident's next target based on the movement-trajectory. E.g., when Mary is moving towards the bathroom we can prepare the suitable lighting for the time of day.

The 2nd task means to provide an interface for 3D spatial service requests in order to resolve spatial relations between objects. In conjunction with a camera based object recognition system this can support a resident in finding objects. E.g. a search for the "lost glasses" of the resident might result in the advice: "Your glasses are on a middle level in the shelf back right in the bedroom". To resolve 3D spatial relations the *spatial query language* of Borrmann [4] is currently investigated.

The 3rd task, a prerequisite for the 1st and 2nd, means to ensure consistency between the model and the real world – i.e. if objects are moved around, the model has to be adapted accordingly. This has been accomplished by integrating the Ubisense positioning system and by manipulating IFC entities by use of the Open IFC Tools Toolbox [5].

III. The Living Place Ontology

For the high level interpretation we have chosen the activity theory from Greenberg [6], which uses activities to describe a situation. An activity consists of an actor, a location, a time period and mainly an item which is involved in the activity.

On this interpretation layer the model of the environment is mapped onto an ontology (cf. Fig. 2), which combines location and spatial information with activity and time information. Within this model we are able to describe behavior patterns in detail. E.g. "having breakfast" is part of the ontology. Here Mary's breakfast takes place in the morning, with her standing in a close range to the table in the kitchen.

In order to detect sequences and dependencies between patterns we are currently investigating the approach proposed in Bohlken et al. [7]. They describe how to match entities from an airfield against the individuals of the ontology. Entity recognition is based on video data with poor accuracy. With a Bayesian network, which assigns probability values to recognized entities, they get good results out of poor raw data.

As far as entity recognition in our environment is concerned, the building model delivers the position of the resident and the relation to any known entity in the living place. With this knowledge we have a small uncertainty in matching the entities in the living place with the individuals of the ontology.

The difficult part in behavior pattern recognition is the range of possible actions and behaviors within daily life. Also some activities can only be recognized when they are finished. E.g. going into bed starts with the trajectory towards the bed and ends in the bed. The trajectory with the direction towards the bed gives a hint to the activity "going to bed" but it is uncertain if it really ends in the bed. So we are planning to use a Bayesian Network to express the level of correctness.

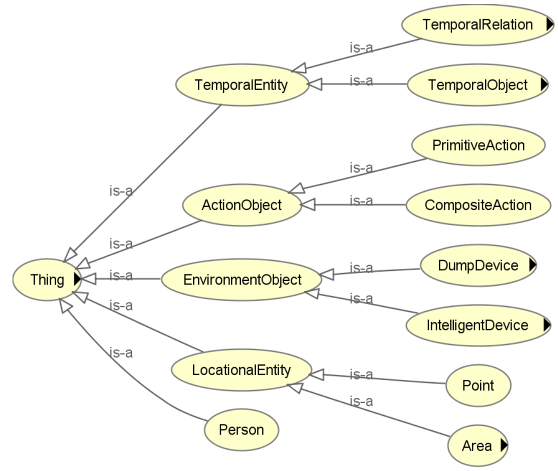

Fig. 2. Living Place Ontology

IV. Future Work

Regarding the *Indoor Spatial Information Service* it is important to deal with the inaccuracy of positioning information (therefore the Kalman filter is currently investigated). It is also considered to filter the spatial entities of a spatial service request by their importance to human spatial cognition.

The ontology is a finite model and it is impossible to implement all characteristics of activities in order to recognize them. Also, if the environment changes, the model has to be adapted accordingly. Therefore we are going to examine whether the approach in [7] can be extended with dynamic attributes and appropriate classifiers.

References

[1] P. D. K. von Luck, P. D. G. Klemke, S. Gregor, M. A. Rahimi, and M. Vogt, "Living place hamburg – a place for concepts of it based modern living," Hamburg University of Applied Sciences, Tech. Rep., Mai 2010.

[2] J. Ellenberg, B. Karstaedt, S. Voskuhl, K. von Luck, and B. Wendholt, "An environment for context-aware applications in smart homes," in *to appear in: International Conference on Indoor Positioning and Indoor Navigation (IPIN), Guimaraes, Portugal*, 2011.

[3] B. Karstaedt and B. Wendholt, "Anwendungen des IFC Produktdatenmodells in intelligenten Wohnungen," *Forum Bauinformatik 2010*, vol. 1, p. 8, August 2010.

[4] A. Borrmann and E. Rank, "Specification and implementation of directional operators in a 3d spatial query language for building information models," *Advanced Engineering Informatics*, vol. 23, no. 4, pp. 370–385, 2009.

[5] J. Tulke, E. Tauscher, and M. Theiler, "Open ifc tools – processing / visualisation / 4d," zuletzte gesichtet am 22.11.2010. [Online]. Available: http://www.openifctools.com

[6] S. Greenberg, "Context as a dynamic construct," *Hum.-Comput. Interact.*, vol. 16, no. 2, pp. 257–268, 2001.

[7] W. Bohlken, P. Koopmann, and B. Neumann, "Scenior: Ontology-based interpretation of aircraft service activities," University of Hamburg, Tech. Rep., 2011.