An Environment for Context-Aware Applications in Smart Homes

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

***Abstract*—The research of adaptive systems has a long tradition in different fields of computer science. Especially in the area of ambient intelligence context aware systems play a key role towards smart environments. Position data are in many approaches the basis for context interpretation. The interpretation of various combined sensor data however lead to more sophisticated models. Experiments in smart home settings allow the validation of the combination of context theories. A flexible system architecture with the possibility for easy integration of new sensors in combination with a rule-based semantic interpretation engine for fast changes of a situational guess allows complex experiments in adaptive environments. This paper describes first steps towards an adaptive living environment setting. The overall architecture is given as well as the interpretation processes for context estimations. The role of location information and the semantic building model as basis for the detection of behavior patterns are discussed. Open problems and lines of further research are sketched.**

***Index Terms*—smart home, context awareness, low level context reasoning, spatial service requests, ontology based context interpretation**

Fig. 1. View into the living place

I. Introduction

In this paper we describe a setting for research in adaptive living environments. The living place under construction (cf. Fig. 1) is a loft style urban apartment with dynamic mapping of functions to spaces according to the respective situation of the inhabitant (e.g. bedroom, kitchen, living room). It is a 140sqm apartment is located at the campus of the university. The apartment consists of one large room with different sections for dining, living, cooking, sleeping, and working as well as a separated bathroom.[1] The living place is a complete functional apartment and therefore suitable for making experiments under real life conditions.

All these experiments can be directed through a controller room, i.e. all sensors and effects are freely configurable allowing settings to be influenced in many ways. On the other hand all experiments can be supervised by an integrated usability installation consisting of several cameras, microphones and other modern monitoring equipment.[2]

One aspect in smart home research is the development of location sensors. Kyoung in [5] presents experimental results with pyroelectric infrared sensors. Helal in [6] evaluates ultrasonic sensors to improve location sensor data. In [7] floor embedded sensor networks are presented as one further alternative. Rahal in [8] combines different location sensors in order to improve accuracy. Roy in [9] goes a step further and combines location data and path prediction algorithms to determine future positions. In contrast to these approaches, we focus on the use of location sensors in combination with several other sensor for use in higher level contexts.

One of our research goals therefore is the situation-based behavior of smart environments. To achieve this, people from different disciplines like architecture, light design and interactive design, as well as computer science work together in interdisciplinary development groups. First approaches incorporate the design of different kinds of light installations, intelligent planning scenarios, natural user controls, context aware applications, smart sensor networks, body monitoring and computational furniture.

Our situation estimation is based on context information, stemming from physical sensors like the UWB system for location information[3] as well as from logical information like day of the week, time of the day, or information derived from the internet like weather conditions. The interpretation process within an open architecture has to cover low level sensor and mid level semantic interpretation as well as high level behavior patterns.[4]

Effects of a transition between situations will include ambient light and color. So moving from bed to bathroom on a cold winter morning will result in a specific atmosphere,

[1] Similar living labs are e.g. inHaus [1], tcom Haus [2] and ihomelab [3].

[2] Similar smart homes have been constructed and installed in the past decade. Strese in [4] contains a good overview of smart homes in Germany. They all focus on different technologies to enable the adaptivity of a smart home.

[3] Actually we use the Ubisense system (http://www.ubisense.net)

[4] A similar approach was proposed by [10].

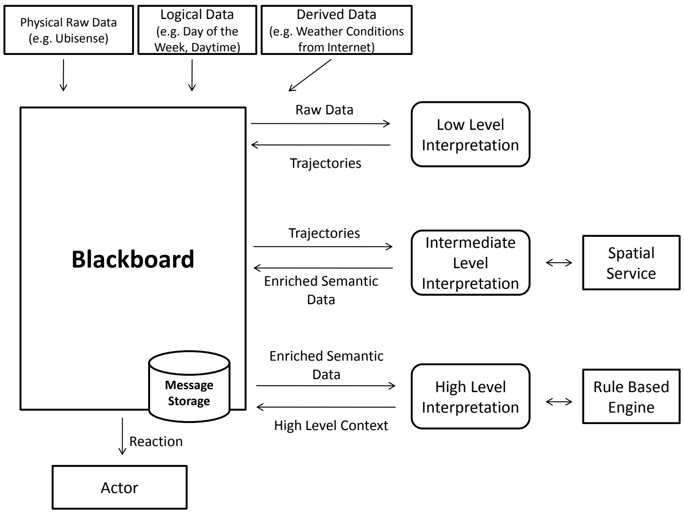

Fig. 2. Architectural sketch

different from the same trajectory on a warm summer Sunday afternoon.

II. Interpretation layers

Our Situation estimation is based on three interpretation layers for context reasoning (cf. Fig 2). The low level interpretation layer, completely relies on raw sensor data and operates without a model of the environment. At the intermediate layer, queries on a 3D building model yield knowledge about spatial entities and spatial relations among each other and to the residents location. At the third layer, a model of typical domain tasks and situations supported by a domain ontology allows to detect and react to behavioral patterns of residents. Fig. 2 sketches the interaction between these three layers.

A. Low Level Interpretation Layer

On the low level we are investigating the capabilities of model independent reasoning. The objective here is to derive context-information from raw physical sensor data without an explicit model of the environment. Only physical sensor data are used to generate knowledge for context-reasoning. E.g., we are able to create trajectories on continuous position data measurements and may derive if, during a certain time period, no new trajectories with significant deviations occur, a residents stays in a certain area. This context information can cause a location shift to the place to stay. E.g., lights and equipments in others areas will fade or turn off, those in the place to stay will become active.

One major advantage of this approach is it's flexibility and generalizability. The results can be transferred to other environments without the creation of an explicit model of new environments. Our goal is to examine limits of model free reasoning for context information extraction, i.e., how much reasoning we might perform without the use of an explicit model. Without a model we can detect the area a resident stays in. But we can't distinguish whether a person is inside a functional space of a specific device, e.g. a screen or a stove. Therefor we'll need knowledge about the spatial environment.

B. Intermediate Level Interpretation Layer

On the intermediate level – a model-based approach – we use the *Indoor Spatial Information Service* [11](ISIS) in order to enrich the context-information with semantic information based on spatial entities and their relations. A detailed three-dimensional semantic building model (see Fig. 3) is used to interpret raw positioning data of objects and residents. This far ISIS supplies information of entities (e.g. door, window, furniture), their spatial relations and allows for classification due to a spatial taxonomy.

Combining the digital building model and the positioning information of the residents allows for intermediate context interpretation. We are able to provide detailed continuous information about the whereabouts of the resident – e.g. the movement from the kitchen to the living room and the abidance inside a functional space (e.g. of an oven, chair or screen). The model-based approach gives us the opportunity to predict a resident's next target based on the movement-trajectory (e.g. in direction to a door, the bed or the kitchen).

On the one hand, ISIS acts as a constant publisher of semantically enriched information in our overall system architecture. Other agents can combine this information with additional sources to derive higher level interpretations. On the other hand, ISIS acts as a provider for direct spatial service requests. E.g. a search query for the "lost glasses" of the resident returns "the glasses are *on top of* the table *in* the living room". In both cases, the reliability of ISIS's spatial knowledge depends on the consistency between the entities in the spatial model and their physical counterparts. In order to stay consistent with the real world, position changes of mobile objects (e.g. furniture) are tracked (with the aid of Ubisense) and dynamically updated in the static building model.

Spatial queries in ISIS are based on an IFC[5] building model. Spatial relations are discovered in 3D applying the approach proposed in [12], where a spatial 3D query language resolves metrical, topological and directional relations[6].

In the current state of development we think that model-based reasoning gives good immediate assumptions without the need of test data. Disadvantages of a model-based approach are 1) the cost for model creation and 2) the consistency problem as discussed above. Advantages of a model based approach are the ability to assign functions to spatial entities, assemblies of entities and areas which in turn are the basis for an adaptive behaviour of a smart home. On the other hand, a model based approach allows for higher level trajectories in terms of spatial objects that serve as input for a behaviour and task based reasoning, i.e. the following high level interpretation of context information is thus in the position to

[5]We took CityGML into account, but decided to use the Industry Foundation Classes (IFC) because of the highly detailed indoor modelling capabilities and the rich range of software in the area of building information modelling (BIM).

[6]Credit is due to André Borrmann from TU-Munich for making the implementation available for us.

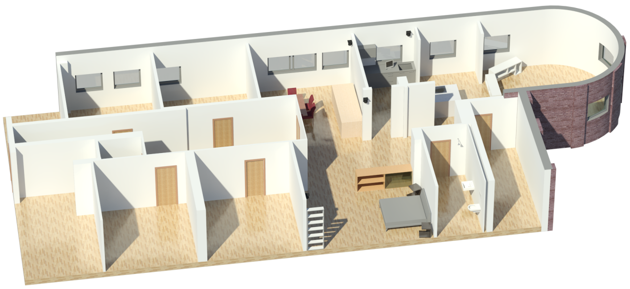

Fig. 3. A rendered view of the living place IFC building model

recognise daily routines (such as *cooking*) based on trajectories and functional spaces.

C. High Level Interpretation Layer

According Abowd et al. [13] context can be every data in the living situation of a person. Following this, context is the low level information as well as the high level information. For the high level we have chosen the activity theory from Greenberg [14], which indicates the activity to describe the context. The activity consists of an actor, the person performing the activity, a location where it takes place, a time period and mainly an item which is involved.

On the high level interpretation layer we have developed a model of the environment which combines location and spatial information with activity and time information. Within this model we are able to describe the context in detail and are able to detect sequences and patterns of actions and dependencies between them. Here we have adapted the approach proposed in Bohlken et al. [15]. They describe how to match entities from an airfield against the individuals of the ontology. To recognize entities they use video data with poor accuracy. To determine the probability of recognized entities a Bayesian network is used. With the Bayesian network they are able to get good results out of poor raw data.

As far as entity recognition (object detection) is concerned, our project uses many different types of sensors with good accuracy. These are an indoor positioning system, object recognition from camera data, capacitive sensors in different kinds of furniture, digital switches, just to mention a few. Therefor we are confident to get reliable results for entity recognition. Our ontology already contains a fixed set of individuals (e.g. bed, shower, sleeping, washing), so that mapping procedures between properties observed in the environment and the individuals in the ontology will be the next working step. The objective is to match between physical entities and individuals in the ontology with a substantial likelihood. With a rule-based engine we are going to detect the action out of the existing individuals of the ontology. Compared to the low and intermediate level the disadvantage of this approach is that we stick to the model as it is. The ontology is a finite model and it is impossible to implement all possible activities in order to recognize them. Also, if the environment changes

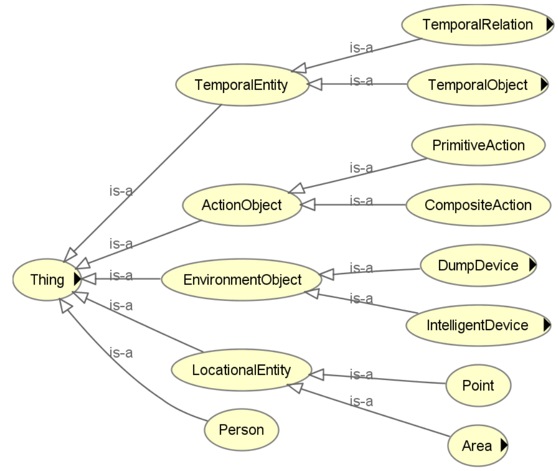

Fig. 4. Ontology for high level interpretation

the model has to be adapted accordingly. Therefore we are going to evaluate the high level information with the results of the model independent information to determine which serves best.

III. State of Work

First experiments with the integration of low and intermediate level interpretation layers for location-based applications in smart homes were performed. For this we implemented a scenario, which selects the TV screen depending on a person's location. This requires an architecture for distributed interaction between different components. Fig. 2 shows that we use a message queue blackboard system [16] (technically based on ActiveMQ[7] and a document-orientated database[8]) for our integration tasks. All sensor data from different interpretation layers are distributed by means of message queues. The architecture allows for the separation of producer consumer pairs towards more loosely coupled relationships, where exchange of components becomes easy feasible. Ubisense, our primary location sensor, has been integrated as one supplier of physical raw data. Capacitive sensors in sofas are tested as further data sources. Currently, we are evaluating various clustering procedures to filter out inaccuracies of sensor data. Next steps are interpolation of sensor data to trajectories in order to learn about typical moving profiles of residents in a smart home.

The ISIS service is fully integrated into the communication platform as well as a product model server [17]. The Open IFC Tools [18] are used for live visualisation and modifications of the building entities. Currently, a library for spatial operators [12] is integrated into ISIS. In addition to spatial reasoning in the area of Building Information Models where quantitative spatial constraints ensure the consistency of spatial facts [19] our future research will consider imprecise position data and filtering queries with respect to the relevant objects and areas, taking the human's field of view into account.

[7]http://activemq.apache.org
[8]http://www.mongodb.org

On the high level interpretation layer we have started the development of an ontology for our smart home, based on the activity theory from Greenberg [14]. This model is already implemented with a couple of typical activities of a ”normal” day. Further steps are to examine rule engines for activity recognition from low and intermediate level context data.

IV. Conclusion and future work

To get the vision up and running our next steps are:

- Integration of miscellaneous sensor data, especially the logical and derived data
- Implementation of low level interpretation to close the gap between raw data input and the intermediate level
- Implementation of context models for selected scenarios successively extending the project ontology on the high level interpretation layer
- Research in the area of behavior patterns in order to detect specific resident situations that serve as input for a rule engine
- In contrast to [15] we have to deal with a great variety of different possible activity patterns. Here we are going to develop new solutions in cooperation with Bohlken et al.
- Conception for the incorporation of a rule engine. This will undergo several refinements, when it becomes integrated with the interpretation of behavior patterns

For us it is vital to test hypotheses in early prototypes. Whereas our current prototypes are short-cuts, where small applications directly interpret location data bypassing the three levels of interpretation, the next prototype will go a step further towards an adaptive smart home. We are working on situation adaptive lighting with changing atmospheres and will compare to a flexible and controllable lighting system which is currently installed at the living place in cooperation with designers.

Since we have chosen an open multilayered architecture, we can easily extend the types of physical sensors. We are planning to incorporate camera-based motion detection based on frame differencing as an additional source for location data. Because of first promising experiments with time-of-flight cameras and the Kinect sensor, we are planning to use person and object detection as an additional location sensor.

Our first experiments show similar results between the three approaches. In our future work we expect to combine the positive effects of each approach for further improvements.

References

[1] Fraunhofer-Gesellschaft, “inHaus – Innovationszentrum der Fraunhofer Gesellschaft,” 2010, letzer Zugriff 30.6.2010.

[2] TCom, “Herzlich Willkommen im TCom Haus,” letzter Zugriff 1.7.2010.

[3] A. Klapproth and D. von Arx, “Wo Intelligentes Wohnen zuhause ist,” iHomeLab – Schweizer Denkfabrik und Forschungslabor, Tech. Rep., 2010.

[4] H. Strese, “Smart Home in Deutschland,” *Ambient Assisted Living – AAL*, p. 46, 2011.

[5] K. N. Ha, K. C. Lee, and S. Lee, “Development of pir sensor based indoor location detection system for smart home,” in *SICE-ICASE, 2006. International Joint Conference*, 2006, pp. 2162 –2167.

[6] S. Helal, B. Winkler, C. Lee, Y. Kaddoura, L. Ran, C. Giraldo, S. Kuchibhotla, and W. Mann, “Enabling location-aware pervasive computing applications for the edlerly,” *Pervasive Computing and Communications, IEEE International Conference on*, vol. 0, p. 531, 2003.

[7] Y. Kaddoura, J. King, and A. Helal, “Cost-precision tradeoffs in unencumbered floor-based indoor location tracking,” in *From smart homes to smart care: ICOST 2005, 3rd International Conference on Smart Homes and Health Telematics*. Ios Pr Inc, 2005, p. 75.

[8] Y. Rahal, H. Pigot, and P. Mabilleau, “Location estimation in a smart home: system implementation and evaluation using experimental data,” *Int. J. Telemedicine Appl.*, vol. 2008, pp. 4:1–4:9, January 2008. [Online]. Available: http://dx.doi.org/10.1155/2008/142803

[9] A. Roy, S. K. D. Bhaumik, A. Bhattacharya, K. Basu, D. J. Cook, and S. K., “Location aware resource management in smart homes,” *Pervasive Computing and Communications, IEEE International Conference on*, vol. 0, p. 481, 2003.

[10] T. Gu, H. K. Pung, and D. Q. Zhang, “A service-oriented middleware for building context-aware services,” *J. Netw. Comput. Appl.*, vol. 28, no. 1, pp. 1–18, 2005.

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

[12] 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.

[13] G. D. Abowd, A. K. Dey, P. J. Brown, N. Davies, M. Smith, and P. Steggles, “Towards a better understanding of context and context-awareness,” in *Proceedings of the 1st international symposium on Handheld and Ubiquitous Computing*, ser. HUC ’99. London, UK: Springer-Verlag, 1999, pp. 304–307. [Online]. Available: http://portal.acm.org/citation.cfm?id=647985.743843

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

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

[16] L. D. Erman, F. Hayes-Roth, V. R. Lesser, and D. R. Reddy, “The hearsay-ii speech-understanding system: Integrating knowledge to resolve uncertainty,” *ACM Comput. Surv.*, vol. 12, no. 2, pp. 213–253, 1980.

[17] J. Beetz, R. de Laat, L. van Berlo, and P. van den Helm, “Towards an open building information model server – report on the progress of an open ifc framework,” *10th International Conference on Design & Decision Support Systems in Architecture and Urban Planning*, 2010.

[18] 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

[19] A. Borrmann and J. Beetz, “Towards spatial reasoning on building information models,” in *Proc. of the 8th European Conference on Product and Process Modeling (ECPPM)*, 2010.