An Ontology for Wearables Data Interoperability and Ambient Assisted Living Application Development

Natalia Díaz-Rodríguez[x], Stefan Grönroos[x], Frank Wickström[x], Johan Lilius[x], Henk Eertink[z], Andreas Braun[u], Paul Dillen[p], James Crowley[v], Jan Alexandersson[w]

[x]Åbo Akademi University
Turku, Finland
ndiaz@decsai.ugr.es, frwickst@gmail.com
{stgronro, jolilius}@abo.fi

[z]Novay, Netherlands
e.h.eertink@saxion.nl

[u]Fraunhofer IGD, Germany
andreas.braun@igd.fraunhofer.de

[p]Philips Research, Netherlands
paul.dillen@philips.com

[v]INRIA Grenoble, France
James.Crowley@inria.fr

[w]DFKI GmbH, Germany
janal@dfki.de

***Abstract*—Over the last decade a number of technologies have been developed that support individuals in keeping themselves active. This can be done via e-coaching mechanisms and by installing more advanced technologies in their homes. The objective of the Active Healthy Ageing (AHA) Platform is to integrate existing tools, hardware, and software that assist individuals in improving and/or maintaining a healthy lifestyle. This architecture is realized by integrating several hardware/software components that generate various types of data. Some examples include heart-rate data, coaching information, in-home activity patterns, mobility patterns, and so on. Various subsystems in the AHA platform can share their data in a semantic and interoperable way, through the use of a AHA data-store and a wearable devices ontology.**

This paper presents such an ontology for wearable data interoperability in Ambient Assisted Living environments. The ontology includes concepts such as height, weight, locations, activities, activity levels, activity energy expenditure, heart rate, or stress levels, among others. The purpose is serving application development in Ambient Intelligence scenarios ranging from activity monitoring and smart homes to active healthy ageing or lifestyle profiling.

I. Introduction

The ageing of the world population is triggering a large set of projects aiming at the implementation of intuitive Ambient Intelligence homes based on universal design approaches and specifically tailored for elderly and disabled persons [1]. Examples of project using wearables are i2home [1] or EIT Digital Active Healthy Ageing Platform[1]. Within this context, we developed an architecture for the aggregation of sensor data for Ambient Assisted Living applications [2]. The project platform, among other elements, was composed of a) a Smart-M3[2] triple storage box that provides an RDF storage [3] for multimedia, interfaces to sensors and actuators, and computational capabilities on an energy-efficient computational platform [4], b) a unified protocol for interfacing sensors and actuators to the platform, and c) programming tools for easy generation of ontology libraries that abstract the access to the data store. The ontology proposed in this paper enables the fast application development and interoperability among heterogeneous devices. The M3 storage supports connecting several M3 boxes together and enables a distributed architecture [5]. M3 provides SSAP (Smart Space Application Protocol) and SPARQL protocols.

One of the features provided by the box is the facilitation of local data processing capabilities for data mining and video processing. M3 storage is a modular and scalable architecture that can also be integrated into e.g. mobile phones, and it supports distribution to facilitate integration of new applications into the box. The Active Healthy Ageing interface between Smart-M3 storage and PHL data store is in 1.

The core objective of the Active Healthy Ageing (AHA) project was to design and implement a distributed service-platform in combination with a few applications that are developed in other Health and Well-being (HWB) activities. The AHA-platform is in itself service-independent: it includes general functions, such as data-distribution, service-control, service-configuration, or application-independent building blocks. The promise of this platform is that it will support services that provide sustainable quality of life improvements. It does this by supporting people to live uncompromised, comfortable, safe, and active even at an advanced age. The AHA-platform can be used by new service-providers, and will

[1]https://www.eitdigital.eu/fileadmin/files/HWB-pictures/EIT-Handout-HWB_EoY-1213-spreads-HR.pdf

[2]Smart-M3 Project: http://sourceforge.net/projects/smart-m3/

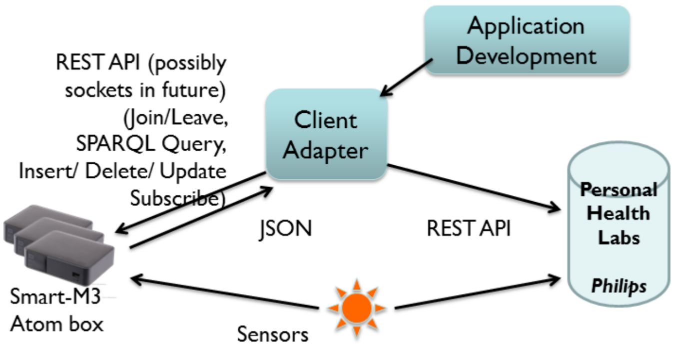

Fig. 1. Active Healthy Ageing interface between Smart-M3 storage and PHL data store

lower their barriers for market-entry. The output is of interest for both SMEs and larger companies: it will allow them to focus on their own added value. This will increase innovation in the HWB area due to lower development and exploitation cost.

The project combined several catalysts and carriers, including an Innovation Radar (to highlight the specific state of the art in AHA-platforms), Test bed and Platforms (for the platform architecture and implementation), and Living Lab Tests (for the showcase applications). The activity's aim, in the context of EIT Digital, was to integrate novel technologies to be integrated on a shared platform. The consortium (consisting of EIT Digital IVZW, Novay, Åbo Akademi University, Fraunhofer Gesellschaft, INRIA, Telecom Italia, Engineering, Philips and DFKI) of this activity involves partners from five EIT Digital nodes: Eindhoven, Berlin, Helsinki, Trento, and Paris. In addition, carrier projects include projects like universAAL (with strong focus on data management and privacy), several mobile/cloud combinations, and projects that focus on connectivity.

The potential users of the AHA platform are application/service developers and, of course, agents that favor to age in a healthy manner. The market/user community size is potentially very big; currently there exist platforms for elderly users, with a very limited and narrow focus on telecare and safety.

II. Active Healthy Ageing Platform Architecture

The Active Healthy Ageing Platform architecture is composed from existing software components and/or frameworks. The integration of the AHA Platform Architecture is therefore a bottom-up activity. As a result of all partners contributions, the AHA platform architecture can be seen in Fig. 2. The blue box shows the platform, and the pink box on top shows services to be integrated with the Philips Personal Health Labs data store.

The core element in this architecture is the Personal Health Labs data store (PHL) that stores enriched information coming from other components/services. We distinguish between various types of APIs:

- *Bi-directional data transfer:* This interaction is represented by the blue arrows, that connect directly to the

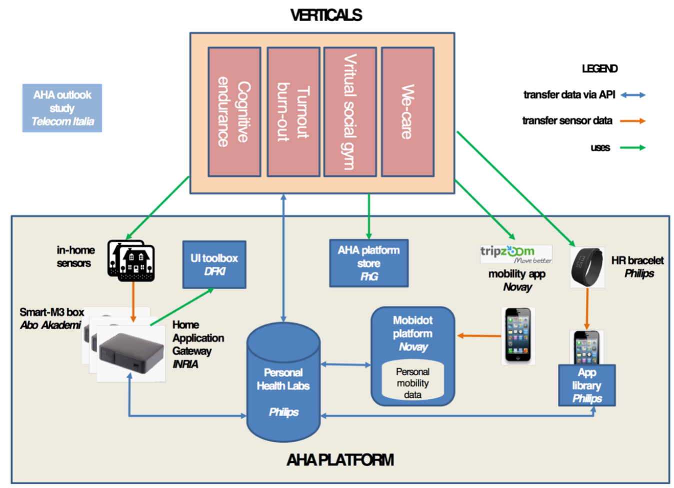

Fig. 2. Active Healthy Ageing Platform Architecture

  PHL data store (Philips). These are RESTful interfaces, and examples of such services are the Home Application Gateway (INRIA, DFKI), the combination of the Mobidot platform[3] and its mobile app (Novay), and the heart rate bracelet and mobile app.
- *AppStore*: The AHA platform supports an AppStore, provided by FHG. The *Universal Remote Control* is integrated with the *AmiQoLT* Integration Platform, while Inria and DFKI integrated their platforms and data elements in the AHA platform.
- *Verticals:* These are application services that connect directly to the PHL data store. These services are developed in other HWB activities, but integrated with the AHA platform. The AHA outlook study was provided by Telecom Italia.

The interaction between the AHA Platform components happens through synchronous interactions (via RESTful interfaces) provided between the PHL data store and its peers:

1) *Home Application Gateway* (developed by INRIA-Grenoble/DFKI/Åbo Akademi), based on sensor data interpretation.
2) *Mobidot MoveSmarter platform* (developed by Novay) interprets mobility data (based on GPS and accelerometer data) and detects individual trips and travel modalities in each trip. The Mobidot platform aggregates sensor data and sends the integrated data towards the PHL data store using a RESTful interface.
3) The *MoveSmarter* platform free app supports both Android and iPhone handsets.
4) *HR bracelet* (Philips) monitors heart-rate and derived features like stress levels. It is connected via low-power Bluetooth to a mobile phone that stores the bracelet data in the PHL data-store. The four identified verticals will integrate their sensor data with the PHL data-store.

The definition of the interface between the Home Applica-

[3]http://www.mobidot.nl/en/index.php

tion Gateway/Smart-M3 Box and the PHL data-store is done via Smart-M3 -based semantic storage box. Using Atom (low-power) board and an RDF store allows for interoperability of heterogeneous information as well as inference reasoning. The AHA platform ontology proposed gathers semantics of different general concepts (users, sensors, physical and physiological variables), while the security/access ontology controls for overall platform data policies [6].

The interface between the Mobidot Platform and the PHL data-store is defined in such a way that the Mobidot platform provides information about the modalities that are used in a single trip. This is the basic mobility information that is stored in the AHA-platform. The Mobidot platform, however, also has support for so-called incentives, a kind-of (virtual and real-world) goodies that can be won by individuals as a reward for proper mobility behavior. The IPersonalMobility interface is responsible for storing and providing so-called trip information (where a trip is an aggregation of modalities used during the specific trip).

The AHA platform application store is a one-stop solution to browse, select, purchase and install new applications that are compatible with the AHA platform. Electronic distribution platforms for software have been around for several decades. While the first systems distributed software without any support for shopping cart or online payment this has become the standard in the last years.

The AHA platform verticals activities produce different software components that either link to the AHA platform from a mobile application or the Home Application Gateway. The mobile systems usually rely on a closed platform and are distributed accordingly. Components developed for the Home Application Gateway should be easily purchasable and distributable over the application server.

III. An ontology for wearables data interoperability

In order to provide the AHA Platform with sensor data interoperability, we propose an AHA platform ontology that includes variables and features to measure vital signs or other physical and cognitive habilities for personalized health. An ontology is a formal representation of entities, relations and properties of a given domain of knowledge. Ontologies represent the main technology for creating interoperability at a semantic level [7]. Through the development of a formal illustration of the data, it is possible to share and reuse an ontology all over the Web. Ontologies formulate and model relationships between concepts in a given domain [8] and are suitable for adding context-awareness capabilities in sensor network systems. Semantic technologies have shown to be successful in context representation and reasoning, which can serve in object tracking and scene interpretation [9], and human activity recognition [10] among other areas.

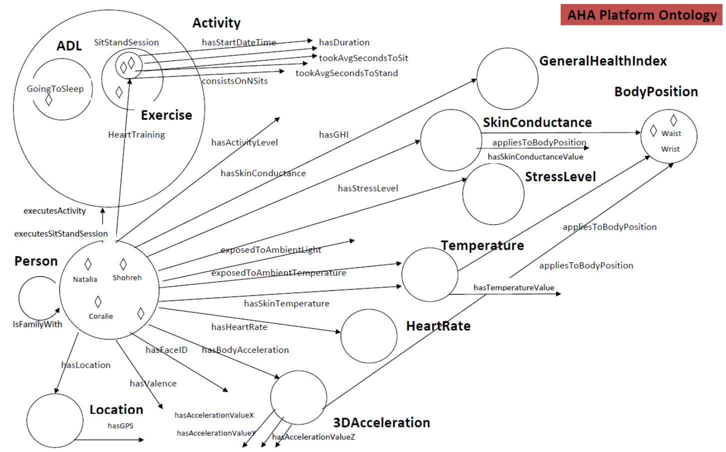

Fig. 3. Wearables AHA Ontology

A. *Ontology entities, relations and datatypes for wearable devices*

By integrating data from different wearable devices and sensors, a set of dimensions or features were selected to be modelled as entities, data properties (literals) and object properties (class-to-class relations). The AHA ontology design consists of a formal specification for the height and weight of the person, the geographical location at which the person is, the logical place at which the person is and logical activity that the person is employing. Other features modelled are the amount of physical activity (exertion) a person is employing, determined at a specific position on the person's body. For each position, maximally one activity count applies at any specific moment. The energy expenditure from physical activity that the person has employed, the heart rate and stress level of the person, the valence of the person, ambient light and temperature that the person is exposed to. More properties are the skin temperature of the person and acceleration at a specific position on the person's body (for each position, maximally one acceleration and skin conductance applies at any specific moment). A summary of the main ontology entities, relations and properties is in Fig. 3.

B. *Applications*

The ontology's vision was designed accounting for the integration into four vertical activities: *Cognitive Endurance, Burn-out turnout, Virtual social gym*, and *We-Care*. Concrete examples on applications of the AHA platform include heart rate unobtrusive motion sensing technologies [11], and different facets of activity recognition in Ambient Assisted Living and health and well-being for healthy ageing lifestyle aspects. Concrete vertical applications in EIT Digital project include *Cognitive Endurance* – which aims at tracking physical activity and heart-rate during the day [12], *Turn out Burnout* – tracking stress, heart rate, activity (lifestyle patterns), sleep [13], etc during daily life [14], and *Virtual Social Gym* – tracking physical fitness (heart rate) and calories burned during a gym session [15].

In general, the applied sensing modalities provided by both sensors and AHA platform are widely applicable and thus enable rapid and low-risk development of applications for third parties in the health and well-being space. Next section shows an application example.

IV. Case study: Remote tracking and monitoring for post-surgery rehabilitation with Kinect

The developed ontology can serve a different range of applications where IoT devices can be connected and information can be shared on a platform independent W3C standard format. In order to test our ontology within the PHL architecture, we developed a remote rehabilitation application. A Kinect for Windows application on remote rehabilitation monitoring/activity recognition, *Rehab@home*, was developed as a case study where the ontology developed served to annotate information useful for both physiotherapists and rehabilitation patients. Rehab@Home encompasses two aspects of health care and well-being: activity monitoring and activity feedback, integrated into everyday lives of (possibly but not uniquely) senior citizens living independently. The application monitors exercise sessions for patients in rehabilitation after shoulder, hip or knee surgery or a simple sit-stand exercise [16]. The final aim is to allow the patient to do the sessions at home giving feedback on the quality and frequency of the exercise to the patient itself and physiotherapist expert, remotely and in real time. The current software allows recording new patterns from different users realizing exercises for the system to learn recognizing them.

Fig. 4 shows the application for remote rehabilitation monitoring and semantic annotation using Kinect for Windows SDK C# Kinect Toolkit and the developed AHA Ontology. The application records, for instance, a sit-to-stand exercise session amount of repetition times, speed, and joints angles. The demo videos are online[4] [5].

For the integration into PHL store, an exercise activity (recognized by Kinect) is inserted with ontological properties *name, started_at* and *ended_at* as specified in the PHL documentation, for instance SitStandSession example:

```
{"name": "SitStandSession",
"ended_at": "2013-08-13 11:32:29",
"started_at": "2013-08-13 11:20:34"}
```

A client library was developed for the integration of the Activity *SitStandSession* into PHL and the construction of a REST API to access the M3 semantic RDF store [4]. A more tutorized deployed application within the project for elders physical, mental and social activation from home is the Virtual Social Gym [17].

V. Conclusion

As a result of the Active Healthy Aging (AHA) Platform project, the definition, design and development of an AHA-platform being the key ambitions of the 2013 Action Line Health and Well-being. The result is a platform that hosts multiple Active Healthy Aging solutions (developed within the action line) on a single platform.

Next to the hosting of the ‘in-house’ developments, the platform needs to be able in the future to address a number of breakthrough challenges that so far have not been addressed in the fragmented market in Ambient Assisted Living for AHA like technical, legal, cultural and international barriers, mobilization, strengthening and integration of local business communities and international scaling.

The ontology was proposed within the context of EIT Digital partnership among European Union partners within the action line Health and Well-being for the Active Healthy Ageing Platform project (2013). This project’s work is part of a starting point, amongst others provided by Philips, INRIA, Novay, Fraunhofer-Gesellschaft and DFKI, to make available a remote monitoring platform also supplied for the Direct Life Labs EIT Digital activity. The future ambition is to create a basic platform with more showcases, higher ambition, and support additional functional and non-functional features.

The wearables Active Healthy Ageing (AHA.owl) OWL 2 ontology aims at serve to both clinical and non-clinical activity tracking and is available online[6]. Reference ontologies developed and used together with AHA ontology are the Kinect Ontology [7][7] and the security and privacy ontology [6][8].

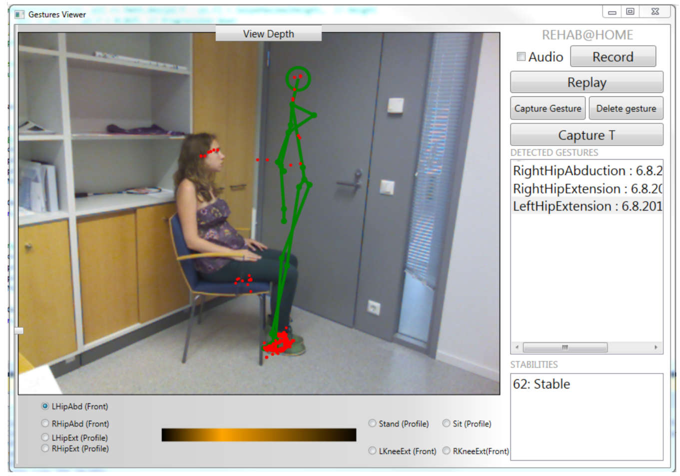

Fig. 4. Kinect remote rehabilitation and monitoring application

Acknowledgment

We acknowledge the support of EU EIT Digital project no. HWB13070 on Active Healthy Ageing within the Health and Well-being action line and the ICT COST Action IC1303 (European Cooperation in Science and Technology), Algorithms, Architectures and Platforms for Enhanced Living En-

[4]Kinect remote rehabilitation demo: https://www.youtube.com/watch?v=XL4JexDNs-Q

[5]Kinect sit-to-stand demo: https://www.youtube.com/watch?v=g8HOtFTk80c

[6]Wearables ontology: https://github.com/NataliaDiaz/Ontologies/blob/master/AHA.owl

[7]Kinect ontology: http://users.abo.fi/rowikstr/KinectOntology/

[8]Security and privacy ontology: https://github.com/NataliaDiaz/SecurityAccessControlOntology

vironments (AAPELE) www.aapele.eu. We thank our project partners Marion Karppi (Turku University of Applied Sciences), Antonio De Nigro and Francesco Torelli (R&D Lab - Engineering Ingegneria Informatica), Iman Khaghani Far (University of Trento), Josef Hallberg (Luleå University), Syed Naseh (We-Care), Rafal Kocielnik (TUE) and Marcos Baez (University of Trento).

REFERENCES

[1] J. Alexandersson, "i2home–towards a universal home environment for the elderly and disabled," *Künstliche Intelligenz*, vol. 8, no. 3, pp. 66–68, 2008.

[2] N. Díaz Rodríguez, "Semantic and fuzzy modelling for human behaviour recognition in smart spaces: A case study on ambient assisted living," Ph.D. dissertation, Åbo Akademi University (Finland) and University of Granada (Spain), 2015.

[3] P. Karvinen, N. Díaz Rodríguez, S. Grönroos, and J. Lilius, "How to choose a semantic RDF store? an scalability analysis for smart space." Submitted, 2016.

[4] F. Wickström, "Getting started with smart-m3 using python," Tech. Rep. 1071, 2013.

[5] A. Berg, P. Karvinen, S. Grönroos, F. Wickström, N. Díaz Rodríguez, S. Hosseinzadeh, and J. Lilius, "A scalable distributed m3 platform on a low-power cluster," in *Open International M3 Semantic Interoperability Workshop*, ser. TUCS Proceedings, J.-P. S. Soininen, S. Balandin, J. Lilius, P. Liuha, and T. S. Cinotti, Eds., vol. 21. TUCS, 2013, p. 49– 58.

[6] S. Hosseinzadeh, S. Virtanen, N. Díaz-Rodríguez, and J. Lilius, "A semantic security framework and context-aware role-based access control ontology for smart spaces." Submitted, 2016.

[7] N. Díaz Rodríguez, R. Wikström, J. Lilius, M. P. Cuéllar, and M. Delgado Calvo Flores, "Understanding Movement and Interaction: An Ontology for Kinect-Based 3D Depth Sensors," in *Ubiquitous Computing and Ambient Intelligence. Context-Awareness and Context-Driven Interaction*, ser. Lecture Notes in Computer Science, G. Urzaiz, S. Ochoa, J. Bravo, L. Chen, and J. Oliveira, Eds. Springer International Publishing, 2013, vol. 8276, pp. 254–261. [Online]. Available: http://dx.doi.org/10.1007/978-3-319-03176-7_33

[8] M. d'Aquin and N. F. Noy, "Where to publish and find ontologies? A survey of ontology libraries," *Web Semantics: Science, Services and Agents on the World Wide Web*, vol. 11, no. 0, pp. 96 – 111, 2012. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S157082681100076X

[9] J. Gómez-Romero, M. A. Patricio, J. García, and J. M. Molina, "Ontology-based context representation and reasoning for object tracking and scene interpretation in video," *Expert Systems with Applications*, vol. 38, no. 6, pp. 7494–7510, Jun. 2011. [Online]. Available: http://dx.doi.org/10.1016/j.eswa.2010.12.118

[10] N. Díaz Rodríguez, O. L. Cadahía, M. P. Cuéllar, J. Lilius, and M. D. Calvo-Flores, "Handling real-world context awareness, uncertainty and vagueness in real-time human activity tracking and recognition with a fuzzy ontology-based hybrid method," *Sensors*, vol. 14, no. 10, pp. 18 131–18 171, 2014. [Online]. Available: http://www.mdpi.com/1424-8220/14/10/18131

[11] A. Braun, R. Wichert, A. Kuijper, and D. W. Fellner, "Capacitive proximity sensing in smart environments," *Journal of Ambient Intelligence and Smart Environments*, vol. 7, no. 4, pp. 483–510, 2015.

[12] A. Hedman and J. Hallberg, "Cognitive endurance for brain health: Challenges of creating an intelligent warning system," *KI-Künstliche Intelligenz*, vol. 29, no. 2, pp. 123–129, 2015.

[13] M. Djakow, A. Braun, and A. Marinc, "Movibed-sleep analysis using capacitive sensors," in *Universal Access in Human-Computer Interaction. Design for All and Accessibility Practice*. Springer International Publishing, 2014, pp. 171–181.

[14] R. Kocielnik, N. Sidorova, F. M. Maggi, M. Ouwerkerk, and J. H. Westerink, "Smart technologies for long-term stress monitoring at work," in *Computer-Based Medical Systems (CBMS), 2013 IEEE 26th International Symposium on*. IEEE, 2013, pp. 53–58.

[15] I. K. Far, M. Ferron, F. Ibarra, M. Baez, S. Tranquillini, F. Casati, and N. Doppio, "The interplay of physical and social wellbeing in older adults: investigating the relationship between physical training and social interactions with virtual social environments," *PeerJ Computer Science*, vol. 1, p. e30, 2015.

[16] N. Díaz Rodríguez, S. Grönroos, F. Wickström, P. Karvinen, A. Berg, S. Hosseinzadeh, M. Karppi, and J. Lilius, "M3 interoperability for remote rehabilitation with kinect," in *Open International M3 Semantic Interoperability Workshop*, J.-P. S. Soininen, S. Balandin, J. Lilius, P. Liuha, and T. S. Cinotti, Eds., vol. 21. TUCS Lecture Notes, 2013, p. 153–163.

[17] I. K. Far, P. Silveira, F. Casati, and M. Baez, "Unifying platform for the physical, mental and social well-being of the elderly," in *Embedded and Multimedia Computing Technology and Service*, ser. Lecture Notes in Electrical Engineering, J. J. J. H. Park, Y.-S. Jeong, S. O. Park, and H.-C. Chen, Eds. Springer Netherlands, 2012, vol. 181, pp. 385–392. [Online]. Available: http://dx.doi.org/10.1007/978-94-007-5076-0_46