Engineering Applications of Artificial Intelligence 35 (2014) 259–276

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

journal homepage: www.elsevier.com/locate/engappai

Generation of human computational models with knowledge engineering

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ARTICLE INFO

Article history:
Received 29 November 2013
Received in revised form
28 May 2014
Accepted 27 June 2014
Available online 27 July 2014

Keywords:
Ambient intelligence systems engineering
Smart environments fast prototyping and testing
Computational models of humans
Knowledge acquisition
Agent-based social simulation

ABSTRACT

The Ambient Intelligence (AmI) paradigm envisions systems whose central entity is the user. AmI integrates technologies such as Artificial Intelligence, implicit Human Computer Interaction, and Ubiquitous Services. Each capability of AmI systems is oriented towards assistance of humans at work, in the classroom, or even at home. In consequence, the AmI development process usually incorporates the final user since the first stages. However, having users available during all this long process is not always possible. Agent-based social simulations where the users' role is played by simulated entities can be used to make the AmI development process faster and more effective. In this scenario, the modelling of *CMHBs* (Computational Models of Human Behaviour) is a major challenge. To address this issue, this paper proposes a methodology whose main contributions are: (1) the use of domain experts' knowledge to create CMHBs; (2) a common methodological framework to develop CMHBs by combining information obtained from sensors' perceptions and experts' experiences; and, (3) open source tools to support this development paradigm. The paper also presents a full case of study in a hospital which illustrates: the number of recommendations made by the methodology; the techniques proposed (mainly the use of ontologies and temporal reasoning); and, the potential of the methodology to model the personnel in a hospital.

1. Introduction

Ambient Intelligence (AmI) is an emerging discipline in information technology, in which people are empowered through a digital environment mainly consisting of complex software and devices (sensors and actuators) connected through a network (Cook et al., 2007). AmI is based on technologies from the following areas: Artificial Intelligence, Human Computer Interaction, Sensors and Ubiquitous Computing. The main goal of AmI is to offer a digital environment which is possible to support the cooperation of the devices, services and people. By using AmI, it is possible to create sensitive, adaptive and responsive scenarios which interact with users seamlessly by providing them with implicit and unobtrusive interaction paradigms. AmI applications are endless: smart homes (Silva et al., 2012), health monitoring and assistance (Suryadevara et al., 2013), hospitals (Cheng et al., 2013), transportation (García-Nieto et al., 2012), emergency services, education (Kaklauskas et al., 2013), workplaces, and etcetera. In all these applications, the user is the central entity. And the usual tendency is the incorporation of groups of users into the development process of AmI systems. Nonetheless, this comes with an extra cost which sometimes is not affordable. There are mainly three phases of the development process in which users are a must: requirements specification, testing, and validation. In all these phases, *agent-based social simulation* (ABSS) is a promising technology which can support AmI development (Serrano and Botía, 2013).

Regarding the requirements specification, AmI systems are a revolutionary paradigm which changes the vision of IT (Information Technology) systems. And new paradigm's particularities are hard to grasp by customers when it comes to explain what AmI systems can do for them. This makes requirements specification a hard task. The use of ABSS allows customers to approach to visualizations of different scenarios and to understand quickly and intuitively the concepts behind the system. Moreover, the customer can criticize and propose new ideas which, in turn, are again simulated and visualized. This iterative fashion of working with requirements has proven to be useful not only in AmI but also in general software engineering.

Concerning testing and validation phases, the most extended approach for testing AmI systems is by using *Living Labs*. These laboratories allow users and researchers to work together in real life environments to evaluate the quality of the services developed. Although this testing approach is intuitive and ultimately necessary, it is possible to anticipate a large number of faults before software deployment using ABSS techniques (Campillo-Sanchez

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http://dx.doi.org/10.1016/j.engappai.2014.06.027
0952-1976/

et al., 2013). This anticipation involves a significant cost reduction in fixing these faults because one of the bases of software engineering is that the earlier a fault is found, the cheaper it is to fix it (McConnell, 2004).

As explained, users are the main entity in AmI systems because these systems provide users with personalized facilities in a non-intrusive way. Therefore, a major issue when studying AmI systems by simulations is the realistic modelling of users and its validation (Garcia-Valverde et al., 2012a). To address this challenging research problem, the authors introduced a methodology called *CHROMUBE* (CHROnobiology for Modelling hUman BEhaviour) (Campuzano et al., 2012a). Unlike a great number of related works which propose methodologies for the agent based modelling, CHROMUBE allows developers to model realistic users with the purpose of helping on various phases of AmI systems' development: requirements specification, testing and validation. The main principles of this methodology are the following: (1) The AmI development process can be enhanced by modelling realistic human behaviours and simulating them. (2) *Chronobiology* (Halberg et al., 1977), which is an area of science which studies how time affects living organisms, can assist in the characterization of human behaviours. (3) Knowledge extracted from sensor data allow creating realistic *CMHBs* (Computational Models of Human Behaviour).

CHROMUBE has been successfully employed to test AmI environments where realistic users were simulated from extensive data retrieved from sensors (Campuzano et al., 2012a; Muñoz et al., 2012). Nonetheless, requiring experiences registered by sensors is an important shortcoming in the methodology. There are a large number of cases where this assumption is simply unfeasible: sensors can be seen as an invasive technology by users; sensors may not be allowed because of ethical reasons; and, more importantly, aspects of users' behaviours may not be accessible by the imperfect vision of the world that sensors are capable of offering, e.g. social interactions.

Due to the aforementioned drawbacks in the methodology, this paper presents an extension of CHROMUBE which allows it to use an additional information source to generate human models: domain experts. This CHROMUBE extension proposal consists of obtaining knowledge about human behaviours from these experts and to model this knowledge with an ontology and timelines. Benjamin et al. (2006) explained that although ontological analysis has been shown to be an effective step in the construction of robust knowledge based systems, the modelling and simulation community, in general, has not enjoyed the benefits of ontology management methods and tools such as the one proposed in this CHROMUBE extension. Due to the ontologies expressiveness limitations related to temporal reasoning, the ontology model is combined with timelines, which have been extensively used for representing the order of the events, tasks and human behaviours. These knowledge models ease to developers the implementation of CMHBs and their subsequent validation.

Although the knowledge engineering techniques that this contribution relies on are not novel, to the best of the authors' knowledge, this paper is the first work where (1) the domain experts' knowledge is aimed at reproducing the behaviour of running AmI systems by simulations; (2) a common methodological framework is given for combining information obtained from sensors and experts' expertise to create realistic agent-based social simulations; and (3) open and free tools are given to allow the interested reader to follow and evaluate the approach presented. These contributions are illustrated with the modelling of users' behaviours during a complete morning in the operating theatre of a Spanish hospital. A number of incorrect assumptions and programming faults were detected thanks to the CHROMUBE extension proposed here. Besides, the resulting models (CMHBs) proved to be a powerful tool to test AmI systems in this hospital and, more specifically, to test indoor location based services.

The paper outline is the following. After revising the related works in Section 2, the CHROMUBE methodology is detailed in Section 3. Section 4 focuses on the last and more challenging phase of the methodology: the validation of the human models produced. Section 5 gives a full case study to illustrate the use of the approach presented and, finally, Section 6 concludes.

2. Related works

CHROMUBE proposes using expert knowledge to develop realistic models of human behaviours. There are many examples of works using the elicitation of knowledge from experts to create realistic model of human behaviours (Bos et al., 1997; Jones et al., 1999). Moreover, some works combine expert knowledge with other information sources. For example, Hattori et al. (2011) combine log data from trials performed on a simulator with expert knowledge in order to identify and formalize driving behaviour models. In the same vein, Murakami et al. (1999, 2005) combine domain knowledge obtained from interviews with data from observations of some simulations for the construction of realistic behaviour models used in a virtual training system. Although most proposals consider several sources of information, such assumption is not always feasible in real scenarios. In many cases, experts are the only information source available. In that sense, Garro and Russo (2010) present the easyABMS methodology. This work is oriented to provide domain experts with a methodology for the agent-based modelling and simulation of complex systems. This methodology is user-friendly and does not require advanced knowledge or skills. However, the expert is in charge of the whole process in this methodology. This requires the domain experts to make a special effort and, in some cases, this causes the simulations to be incorrectly simplified or modelled.

In order to address these issues, this paper presents an extension of the CHROMUBE methodology, which provides full assistance in the process of obtaining computational human models from expert knowledge. This extension offers support from the knowledge capture until the validation of the CMHBs.

Regarding the first step, the knowledge capture, there are several methods for acquiring data about people's activities in their daily lives. These methods can be classified in at least three categories: (1) data collection from sensors, (2) observation-based data collection, and (3) data collection based on survey techniques (Monitoring et al., 2009; Tapia et al., 2004).

In the first group, data collection is made by the use of sensors attached to the body or included in the environment. This method is a promising and relatively inexpensive technique to acquire data about certain human behaviours. Examples of sensors attached to the body are the accelerometers (Amini et al., 2011; Makikawa et al., 2001), biometric wearable sensors (for measuring heart rate, blood pressure, temperature, etc.) (Pantelopoulos and Bourbakis, 2010), sensors integrated into clothes (Pacelli et al., 2006) or sensors integrated into mobile phones or PDAs (Liao et al., 2007). Among the sensors embedded in the environment, typical devices are the following: motion sensors, pressure pads, and door latch sensors (Beth et al., 2003; Orr and Abowd, 2000).

The main advantage of this kind of data collection techniques is that sensors are usually not intrusive for people and they can be easily deployed in actual environments. However, some activities that include complex physical motion and interactions among people cannot be correctly differentiated from others (Serrano et al., 2012; Gutiérrez et al., 2013). Another important disadvantage is that the use of sensors could not be allowed in some scenarios, therefore data must be extracted from other sources.