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An ontology-based approach to conflict resolution in Home and Building Automation Systems

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ABSTRACT

Ambient intelligent systems such as Home and Building Automation Systems (HBAS) are becoming evermore accepted and capable of actuating automatically on behalf of users to fulfil their requests or enable activities. However, when multiple users interact with such systems, the requirements of activities often interfere resulting in conflicting actuations which HBAS ought to automatically detect and resolve. Yet, despite recent advances in HBAS, no ambient intelligent solution has been reported that is adequately grounded on knowledge analysis.

The contributions of this article are twofold. First, it reviews relevant literature on Ambient Intelligence, conflict detection, conflict resolution and knowledge representation in HBAS. Second, it proposes and validates an ontological framework for conflict detection and resolution backed by knowledge-based analysis. Effectively, the proposed solution performs automatic environment actuations maximizing users comfort and energy efficiency.

1. Introduction

Home and Building Automation Systems (HBAS) are systems that control electronic devices and equipment inside home and buildings. Home Automation Systems (HAS) differ from Building Automation Systems (BAS) in the precincts that HAS focus on providing comfort to users in a way that is almost imperceptible for them. BAS, in contrast, aim at maximizing energetic efficiency towards economic benefits, while ensuring an adequate level of service (Echelon, 2003; Siemens, 2012). A growing number of devices in our homes, from lamps (Hue, 2013; LIFX, 2012) to air conditioning units (Aros, 2014; Nest, 2012; Smart-Zone, 2012), besides having a physical interface with buttons, are becoming increasingly autonomous and Internet-enabled (Smartthings, 2012; Staples-Connect, 2013; WeMo, 2013), thus forming a networked intelligent control system. Indeed, in the near future, HBAS will feature so many equipment and devices that it will be virtually impossible to use distinct buttons to handle every single aspect of each one of them. Therefore, Ambient Intelligence (AmI) systems will surface to play a very important role in everyday-life realizing Weiser's landmark vision (Weiser, 1991), and users will be increasingly reliant on them (Bohn, Coroamă, Langheinrich, Mattern, & Rohs, 2005; Weiser, 1993).

Given the ever growing development of intelligent consumer electronics equipment and their capabilities, Home and Building Automation Systems have received increasing attention from the Computer Science community (Merz, Hansemann, & Hübner, 2009). Due to the high variability of user activities and building infrastructures, the implementation of (HBAS) is largely ad hoc. Implementation differ considerably depending on whether it is a small home, a large building, or commercial facility. Implementation might also change among equivalent building structures due to the constantly changing needs of the end-user or the architectural purpose of the building. Overall, infrastructure heterogeneity and the lack of established standards hamper HBAS take off.

The crucial aspect of Ambient Intelligence is the capability to react (or even anticipate) users needs and actuate in a way that is consistent with the users expectations. For this vision to become possible a large number of devices must coordinate themselves and adjust taking into account a large number of variables ranging from environment conditions, to space characteristics or even user's emotional state. Creating these systems poses a number of challenges to computer science. Imagine a system that will adjust the light ambience of a room to match the type of movie being played on the TV that also takes into account the amount of natural

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Nomenclature

HBAS	Home and Building Automation Systems
HAS	Home Automation Systems
BAS	Building Automation Systems
AmI	Ambient Intelligence
UbiComp	Ubiquitous Computing
OWL	Ontology Web Language
OWL-DL	OWL-Description Logic
RDF	Resource Description Framework
SPARQL	SPARQL Protocol and RDF Query Language
CSP	Constraint Solving Problem
SAT	Satisfaction Problem

light entering the room, thus closing the window blind if required. However, multiple contexts may coexist inside an automated environment triggering distinct actuations that may conflict with each other. Existing literature address conflict resolution in HBAS through simple resource management or priority rule mechanisms (Armac, Kirchhof, & Manolescu, 2006; Huerta-Canepa & Lee, 2008; Retkowitz & Kulle, 2009). Moreover, ontology-based approaches do not encompass query knowledge analysis for energy efficiency (Corno & Razzak, 2012; Wicaksono, Rogalski, & Kusnady, 2010).

Consequently, it is still necessary to develop automation systems able to intelligently reason about relevant environment conditions extracted from models that represent buildings in terms of automated spaces and the services that they offer. This article presents an ontology-based solution that performs knowledge analysis by means of queries to infer context. The system models conflict and energy efficiency optimization as instances of Constraint Solving Problem (CSP) in order to perform environment actuations from the attained solutions.

1.1. Motivation

Consider a living room equipped with an automation system prepared to accommodate different activities. Suppose that Alice is reading inside the room with the ceiling lamp set to 500 lumen/m^2 (lux). Suppose moreover that Alice's user profile dictates that, for reading activities, her luminance preference ranges from 450 to 550 lux. Now, when another person enters the living room it may have different preferences regarding luminance levels. Distinct preference intervals trigger different responses from the system upon the entrance of a second person in the room. In particular:

Preference constraint:
An occupant enters with luminance preference of 490–590 lux. There is no conflict and the current luminance state complies the preference interval of both users.

Preference overlap:
An occupant enters the room with luminance preference interval of 505–550 lux. This situation represents a conflict since the luminance in the room is set for 500 so the second user's preference is not met. It is possible for the system to adjust itself to satisfy both persons. In this case adjusting lux levels to 510 would resolve the conflict.

Preference disjointness:
When an occupant with a preference interval of 560–600 lux enters the room, there is no possible system action to accommodate the luminance preferences of both users. The preference intervals never intersect. In this case the system could either maintain its state or inform the users of its inability to resolve the conflict.

Another example of this sort of situation would be user A wanting to do a home cinema session while user B tries to read in the same room. In this case, user A's activity is disturbing user B's activity, because it is not possible to read in the dark while, at the same time, the volume of the video is relatively high in order to set a proper cinema home theatre. The same way it is flat to watch a film where the sound volume is extremely low. There are cases where is not possible to meet all user's needs, so the goal would be for the system to dynamically adapt itself to satisfy the majority of them.

Fig. 1 illustrates four distinct scenarios where preference constraint, disjointness and overlap occur due to the presence and entrance of users inside an automated space.

Clearly, in everyday life, people often perform distinct simultaneous activities inside shared spaces, which compete for the same resources and cause side-effects making them interfere with each other. The occupants of those spaces require certain environment parameters in order to perform those activities effectively. The requirements of each user result in different system setups to accommodate each user's intended scenario. Naturally, some scenarios may coexist in a same space but in many cases the scenarios may not co-exist leading to a *conflict* situation where one activity is hampered by the scenario of another.

1.2. Contributions

Conflict detection and resolution in Ambient Intelligence is still a relatively new issue with few reports on intelligent environment systems addressing this topic (Resendes, Carreira, & Santos, 2013).

In order to validate the proposed hypothesis, this research work surveys relevant works within the scope of Ambient Intelligence, ontological reasoning and conflict detection.

Our proposed solution is backed by an automated reasoner that explores a knowledge-based representation of the environment. The representation is encoded by an ontology model that provides semantic information over the environment domain. This will result in an accurate and semantically rich representation of environments and entities, respectively. Concepts such as activities, spaces, services, users and environment variables are associated among each other through meaningful relations. Conflict detection will be achieved by means of SPARQL Protocol and RDF Query Language (SPARQL) queries to this model, and subsequently, conflict resolution will be attained by finding the most favorable combination of services by performing constraint solving.

Another distinguishing aspect of the solution detailed herein is that the conflict resolution approach can also be used to manage and maximize energy efficiency in the environment. This is achieved by checking for conflicts, not only among activities or user intentions, but also among system actuations that may impact energy consumptions.

We should note that existing universal reasoners allow detecting problems and inconsistencies in the requirements defined using an ontology language. However, the proposed solution in the context of HBAS is not limited to dealing with a reasoner inconsistency message. Instead, our work imports the detected conflicts into the framework through dedicated data structures. This