Contents lists available at ScienceDirect

Pervasive and Mobile Computing

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

Fast track article

Planning meets activity recognition: Service coordination for intelligent buildings

Ilche Georgievski *, Tuan Anh Nguyen, Faris Nizamic, Brian Setz, Alexander Lazovik, Marco Aiello

Johann Bernoulli Institute, University of Groningen, Nijenborgh 9, 9747 AG Groningen, The Netherlands

ARTICLE INFO

Article history:
Received 11 March 2016
Received in revised form 2 December 2016
Accepted 16 February 2017
Available online xxxx

Keywords:
Service composition
AI planning
Activity recognition
Building automation

ABSTRACT

Building managers need effective tools to improve occupants' experiences considering constraints of energy efficiency. Current building management systems are limited to coordinating device services in simple and prefixed situations. Think of an office with lights offering services, such as turn on a light, which are invoked by the system to automatically control the lights. In spite of the evident potential for energy saving, the office occupants often end up in the dark, they have too much light when working with computers, or unnecessary lights are turned on. The office is thus not aware of the occupants' presence nor anticipates their activities. Our proposal is to coordinate services while anticipating occupant activities with sufficient accuracy. Finding and composing services that will support occupant activities is however a complex problem. The high number of services, the continuous transformation of buildings, and the various building standards imply a search through a vast number of possible contextual situations every time occupants perform activities. Our solution to this building coordination problem is based on Hierarchical Task Network (HTN) planning in combination with activity recognition. While HTN planning provides powerful means for composing services automatically, activity recognition is needed to identify occupant activities as soon as they occur. The output of this combination is a sequence of services that needs to be executed under the uncertainty of building environments. Our solution supports continuous context changes and service failures by using an advanced orchestration strategy. We design, implement and deploy a system in two cases, namely offices and a restaurant, in our own office building at the University of Groningen. We show energy savings in the order of 80% when compared to manual control in both cases, and 60% when compared to using only movement sensors. Moreover, we show that one can save a figure of €600 annually for the electricity costs of the restaurant. We use a survey to evaluate the experience of restaurant occupants. The majority of them are satisfied with the solution and find it useful. Finally, the technical evaluation provides insights into the efficiency of our system.

1. Introduction

The effective and efficient operation of buildings depends on the capabilities of their management systems. These are control systems for individual buildings (or groups of buildings) that use computers and other devices for monitoring, data

* Corresponding author.
E-mail address: i.georgievski@rug.nl (I. Georgievski).

http://dx.doi.org/10.1016/j.pmcj.2017.02.008
1574-1192/

Please cite this article in press as: I. Georgievski, et al., Planning meets activity recognition: Service coordination for intelligent buildings, Pervasive and Mobile Computing (2017), http://dx.doi.org/10.1016/j.pmcj.2017.02.008

storage and communication [1]. In modern buildings, examples of devices include actuators, such as switches on ceiling lamps, movement detectors, and light sensors. Commonly considered capabilities of the building management systems include heating, ventilation and air condition control, lighting control, hot water control, and electricity control. The general objective of these systems is to improve occupants' experiences often under the constraints of energy efficiency [2].

With their current capabilities, building management systems can easily deal with triggering a single *service* or even a predefined sequence of services. Services here represent the functionalities of devices given that the development of building management systems is migrating to service-oriented architectures, as illustrated in [3,4]. An example of a service is turning on lights in modern office buildings using movement detectors. This building operation is supposed to reduce the energy consumption of lighting by 50% [5]. In these scenarios, the lights usually stay turned on until after some predefined time after detectors stop sensing movements. This operation is perfectly fine when the occupant, let us say Theodore, has left his office. Often, unfortunately, the lights go off while Theodore is still in the office and performs an activity, such as reading, for which the detector cannot observe his movements. The indication is that the building is neither aware of Theodore's presence nor anticipates his behaviour. The implication might be that the building does not even save as much energy as possible under such circumstances. For example, the activity of Theodore may require no light at all, or if it requires, the natural light might be sufficient. In any case, the building misses to provide intelligent responses.

The problem

Creating an aware and responsive building environment that enables occupants to have a truly immersive experience requires that the building management systems react to occupants with plausible levels of understanding of the situations and occupant activities. The systems can accomplish this by *service coordination*, which represents the task of composing a sequence of services while anticipating the activities of occupants. Service composition is the process of finding and arranging services in an order that satisfies a given objective. Service coordination motivates the following aspects to be considered. First, the approach to service coordination has to be able to deal with a high number of services. Say that a modern office building makes use of ten services for monitoring and control per desk. If the building has five floors each with 50 offices with two desks, as many as 5000 services can be expected, excluding those for corridors, social corners, meeting rooms, etc. Second, the approach needs to support the transformation of buildings. That is, devices may change, their services may constantly appear and disappear, and the state of the devices may continuously change. Third, the approach has to be able to incorporate and consider various requirements, from occupant needs to building standards. In office buildings, for example, many activities and therefore the performance of occupants depend on the quality of light in offices. For European countries, for instance, the basic light requirements are defined in the European standard for lighting in indoor work places [6]. Finally, the approach should consider as early and as many as possible activities of building occupants. Occupant behaviour has been shown to have a large impact on the demand of space heating, cooling and ventilation, lighting and appliances in buildings [7].

Considering these aspects, a *building coordination problem* involves a search through a high number of possible contextual states every time occupants perform some activities. Finding the compositions of services that will satisfy the requirements needed for performing the activities then becomes a complex task. A solution to this building coordination problem is to perform the service composition automatically and dynamically, assuming that occupant activities are identified as early as possible during the coordination. Doing this should maximise occupant comfort (or, similarly, minimise occupant disruption) possibly under the constraints of minimal energy consumption.

Once a sequence of services that anticipates the activities of occupants is found, the next step is to execute the services in the building environment. Therefore, the second problem that we address is how to efficiently execute services when the environment changes due to external factors, or services happen to fail at execution time.

Proposed solution

Existing control approaches show limited capabilities in addressing the complexity of building environments. First, preprogrammable timers and set points simply cannot address the requirements of buildings (e.g., dynamism, service availability, uncertainty, scalability, and support for standards, protocols and policies). Second, the existing platforms for pervasive computing applications, such as Jini (www.river.apache.org), appear to be limited in terms of providing only basic (device) interoperation [8]. Third, rule-based approaches, which provide more complex control functionalities, are characterised by several drawbacks: (1) a lack of flexibility — all possible situations that may happen in a building environment need to be predicted and covered by (a large number of carefully designed) rules; (2) a lack of systematicity — as the building environment becomes more robust, more rules are added without any enforced systematic steps resulting in a cluttered building management system; (3) a limited service order — creation of ordered or partially ordered adaptations appears to be a challenge (for example, given an objective to close a window, a rule-based approach might create a coordination consisting of, first, pulling down the blinds, and then closing the window); (4) a lack of reusability — reuse, modifications and maintenance across different types of building environments becomes difficult. Two spaces may happen to have some common situations, but if those spaces serve different purposes, say a meeting room and a social corner, then most of their situations will differ.

Please cite this article in press as: I. Georgievski, et al., Planning meets activity recognition: Service coordination for intelligent buildings, Pervasive and Mobile Computing (2017), http://dx.doi.org/10.1016/j.pmcj.2017.02.008