Changing Interactions to Reduce Energy Consumption: Specification of a Context-Aware System Centered on the Home Occupants' Concerns

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Abstract. This paper presents the specification of a context-aware system dedicated to assist home occupants in their everyday life while reducing their energy consumption. The system behavior and the interaction are built upon the definition of "situation spaces" based on a prior definition of the contexts of activity from the point of view of each actor in the home, i.e. taking into account actors' concerns. The interaction specification appears to be a way to manage the discrepancy between users' concerns and the system context, which can reduce errors. To develop context-aware systems that can easily be appropriated and thus potentially "invisible," we believe it is essential to articulate choices about architecture and interaction with models of individual-collective activities built upon real-life observations.

Keywords: Context-aware computing, user-centered design, sustainability, ambient computing, interaction design.

1 Introduction

Our research lies at the intersection of ambient computing and sustainability research. It differs from approaches that seek to reduce energy consumption in the home by influencing people and changing their behavior. Instead, we are working to use context-aware computing to assist home occupants and reduce energy consumption without necessarily requiring intentional actions to achieve this goal. Harris and Cahill referred in [8] to context-aware power management.

Research in the social sciences indicates that energy consumption is not a behavior, but is rather the result of behaviors whose purpose is not generally related to energy savings. Individual activity at home is constituted of multiple lines of different

C. Stephanidis (Ed.): Posters, Part II, HCII 2013, CCIS 374, pp. 638–642, 2013.

concerns which structure the involvement in the activity [7]. However depending on conditions in which the activity occurs, the potential concerns relative to energy management may not be actualized and produce energy control actions. Thus we aim to design a technical system that will take over part of the responsibility for reducing energy consumption, contributing to build sustainable human-environment interactions, and especially sustainable situations; that is, both from householders' points of view (not affecting their activities) and from a sustainable perspective (saving energy).

However, designing context-aware systems to reduce energy consumption implies a prior definition of the contexts in which power management must be implemented in order to guarantee "relevant" actions from the system. According to Dey and Abowd [3], "a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task". This definition links the system actions to those of the user. But ambient computing marks a radical break regarding the user context that needs to be taken into account. The context is no longer the classic conception of machine use, as the "user" is quite likely to be interacting with a computer system while being engaged in a completely different activity. We believe that the design of context-aware systems must be based on a prior definition of the contexts of activity from the point of view of each actor in the home. However, activity models often show that human activity is very complex and that the underlying contexts are difficult to determine [7]. Yet from a system point of view, contexts must be defined by measurable values. If the system context and the human (subjective) context cannot be fully brought together, it is nevertheless vital to assess this discrepancy so that the system can respond in a relevant manner.

This discrepancy between human and machine contexts prevents the system from being fully automatic. However, direct interaction with the user must be limited so as not to be perceived as bothersome. This raises the question of how to strike a balance between automation and direct interaction. In the case of implementing systems for energy management, the system behavior should facilitate the action (ensure light and heating) and energy efficiency (no overuse), but without the need to be initiated by the users, who do not necessarily see themselves involved in interaction [4]. In such a situation, the dynamic transition between the different types of interaction is a key issue to promote invisible use, which allows users to focus on the objective of their activity. System invisibility is not necessarily physical disappearance or having an implicit nature. An invisible system refers to a system that has been appropriated and incorporated into daily practices [6].

2 Presentation of the Implemented System

Our approach required the constant articulation of competence in the fields of cognitive ergonomics and ambient computing. It was structured by a series of steps, presented in the following sections, each of which was instrumental in developing an initial prototype for the home.

2.1 Modeling Domestic Activities

To anticipate the design of future services and context-aware systems, we have developed a research program to analyze home activities in real-life situations and produce models useful for design over several years. Our analysis is based on an initial observation of domestic activities (continuous video recordings of activities, post-recording interviews), transcribed and processed in order to grasp the meaning each occupant gave to his or her own activity. Our results show the different characteristics of collective activities in domestic settings, with implications for the design of ubiquitous technologies, see for ex. [10], [7].

These studies also show that activity at home is constituted of multiple lines of different concerns. Inhabitants manage several activities at the same time with several underlying concerns, which take part in their individual context. For example, someone involved in cooking in the kitchen may also listen to a radio broadcast and be concerned by keeping an eye on a child, waiting for a phone call, and intend to watch a TV show later. A concern can be interrupted in favor of another and be reopened later (for ex. stop cooking to go to see the child, leaving the cooking activity "opened"). In this situation some appliances are still on without necessity (lights, radio) while others (stovetop) must not be necessarily turned off because the activity is paused and not closed.

We used our prior activity analysis to point out the relevant behavior of a context-aware system for typical situations (for ex. not turning off the stovetop but providing distant interaction to remotely take over the unattended stovetop). Then, during the specification phase, it was possible to link an action / non-action of the system with its identification of a situation on the basis of measured values from simple sensors.

2.2 Defining a Technical Architecture to Infer Human Actor's Involvement

We developed an architectural model likely to respond to our objectives and constraints [5]. This model was inspired by the four-layer architectural model suggested by Coutaz and al. [2]. In order to foster the acceptability and adoption of the system by real households, we imposed some constraints on the equipment (no wearable technologies, choice of sensor that minimize privacy concerns, no video cameras, no information about the identity of the occupants). The sensor data (pressure, motion, sound…) are first interpreted into a higher, domain-relevant concept, such as whether a room is occupied. This higher-level concept is called context. Contexts are then combined to infer the occurrence of situations, which are abstract states of affairs of interest to the applications.

The context and situation modeling and reasoning framework we adopted is called context spaces theory [9]. According to this theory, basic contextual information like the presence of a person or the status of an appliance is called a context attribute and is modeled as a dimension in multidimensional space. The values of context attributes are provided either by augmented appliances or as an outcome of sensor data fusion, performed using Belief Functions Theory (also known as Dempster-Shafer or evidence theory [11]). The situation spaces, which model real-life situations, are subspaces defined over regions of acceptable values of selected context attributes. For instance, the situation space "sleeping" can be modeled as the combination of the fact that a person is in a room and that he or she is seated or lying down. The occurrence of situation spaces, detected by reasoning on the runtime context attribute values, provides evidence of the involvement of an actor in some activity. We do not aim to model the reasons underlying the real-world situations. We instead model the particular conditions that solicit a particular action (for ex. regulating the heating). Thus, the same real-world situation can be modeled by different situation spaces and result in different behaviors from the system.

2.3 Defining Services and Designing Interaction

The activity analysis identified the actions that could be assigned to an adaptive ambient system either because they are a help to the flow of activities and/or because they are of interest from an energy point of view, for ex., turning the lights on/off automatically or providing a means to interact through existing interactive devices.

The discrepancy between the system knowledge and the inhabitants' concerns is taken into account during the definition of the system actions for each type of situation. Depending on the detected situation, three modes of contextual interaction are proposed as a way to manage the consequences of the discrepancy: incidental, direct, and direct-incidental.

Incidental interaction is implemented using established clues to automate certain actions: presences/absences, the occupability criterion (rooms near the scene of ongoing activities are considered as more likely to be occupied than others). Depending on the level of confidence attributed on these dimensions, it is possible for the system to act alone, after a time frame to be sure that the action has to be done. We also introduced "mid-level actions": switching off the TV screen but leaving the sound...

When the situation is considered undecidable or potentially dangerous, the system must let the user act. In our previous example, where a stovetop is left switched on while the user is in another room (situation space "monitor cooking"), there is no automatic switching off of the stovetop because it is impossible on the basis of the available information to decide between an oversight (i.e. a dangerous situation) and deliberate action (i.e. leaving a meal to simmer). A direct interaction is presented on the interactive devices in the rooms being occupied (uncertainty about who is the actor).

We also introduced the notion of direct-incidental interaction as a way to anticipate that two concerns might become concurrent, for ex. talking over the telephone while the radio is on. The system must let the users decide whether to mute the radio. It is indeed not possible to ask the user whether to turn off the radio and then allow him or her to answer the call. It is achieved by modifying the phone interface to provide a further action: answer the phone AND turn off the radio.

To these three forms of interaction provided by our script, we can add the direct non-contextual interaction. The user is free to put the entire home, certain rooms, or certain appliances into "auto" mode: this mode means that actions to turn appliances on or off will be performed automatically [10].

2.4 Building Sustainable Situations

We implemented and experimented our distributed architecture, where contextual information is processed by several entities in a collaborative fashion. The system functionalities (automatic actions, provision of information, interaction with users) are carried out by distributed devices and augmented appliances. Every device and augmented appliance runs an implementation of context spaces theory [1] and the resulting functionalities. For this reason, the devices are designed to self-operate in a situation-aware manner, minimizing their energy consumption while preserving user comfort.

3 Contributions and Perspectives

This first implementation was made for a set of situations extracted from real life. We succeeded in taking into account real collective activity and combining criteria to assist human activity with criteria to reduce energy consumption. However, we now need to consolidate the system and widen the situations to test it in real situations and assess the achievement of its appropriability and invisibility.

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