Intelligent Environments 2018
I. Chatzigiannakis et al. (Eds.)

doi:10.3233/978-1-61499-874-7-455

A Context-Aware Smart Office for Improved Comfort and Energy Saving

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Abstract. Smart spaces are defined as a physical space rich in equipment and software services that can interact with people to provide intelligent services to them. The main aim of such spaces is improving inhabitants comfort and contributing to energy saving. Examples of smart spaces include smart offices which are equipped with a set of appliances to improve employee's comfort and contributes to energy saving. However, many employees become frustrated with the difficulty of using the complex functions of their appliances by spending a non-negligible time in configuring and setting these appliances which prevent them from focusing on their main tasks and therefore affect their productivity. One major requirement for smart spaces is context-awareness which allows them to provide the accurate service according to the current context with minimum intervention and in an unobtrusive manner. Previous works did not deal in depth with the context-awareness factor and are limited to a simple automation of appliances inside a smart space. In this paper, we develop and implement a fuzzy based context-aware services adaptation for a smart office where we base our approach on a clear definition of context and methodology for extracting context information.

Keywords. Smart office, context, Context-awareness, Service, Adaptation, Sensor, Fuzzy Logic.

1. Introduction

Embedding computer products into people' s everyday lives have driven research into the paradigm of both ubiquitous computing and smart spaces. So far, there is no explicit or common definition of smart spaces, which are also known as Ambient Intelligence or Ambient Assisted Living. Research on smart spaces tries to move from spaces filled with smart devices and appliances to smart spaces where communication and harmony are imposed (resp. synchronization). Such spaces should personalize themselves in responses to current context changes including user presence, behavior and environment. The most useful definition of smart spaces was proposed by D. J. Cook and S. Das [1]: "Smart space is able to acquire and apply knowledge about its environment and to adapt to its inhabitants in order to improve their experience in that environment". The main goal of smart spaces consists of effectively fulfil the needs of the user and control the environment on behalf of him by configure the devices and appliances present in their environments in a seamless, unobtrusive and non-intrusive way. intelligence in smart spaces reside on the effect that technology can recognize the user's current contexts and providing services accordingly. Context-awareness is a key

enabling factor for the development of smart spaces. In Previous works, each component usually performs a single function and there is no synchronization with other components of the space. In addition, they suffer from not dealing in depth with context-awareness by not relying on a clear definition of context or a clear method for extracting context information. Our aim is to develop and implement a context-aware smart office using fuzzy logic for services adaptation which improve both employee's comfort and energy consumption. We base our approach on both a clear definition of context and a simple method for extracting context elements.
The rest of this paper is organized as follows: In Section (2), we provide some background information about related work. In Section (3), we present context recognition, its extraction and acquisition inside a smart office. In section (4) we detail the development and the implementation of our approach of context-aware services adaptation using fuzzy logic technique. Section (5) provides some concluding remarks and future research directions.

2. Related Work

Considerable effort has been spent for enabling home automation in the last years and several interesting systems for services adaptation in a smart space have been proposed. Different techniques of artificial intelligence (resp. machine learning) have been used to achieve the automatic adaptation task such as bays network, neural network, case-based reasoning, rule-based systems genetic algorithms, KNN, etc. [2-21]. [22] Highlighted research projects employing multi-agent system, action prediction, artificial neural network, fuzzy logic and reinforcement learning. It is found that the combination of tools and techniques are crucial for successful implementation. Some of the previous works used the fuzzy logic technique for services adaptation, we focus on them in this section. [23] Proposed to extract fuzzy membership functions and rules that represent the user's particularized behaviors in an environment. Their proposed technique is an unsupervised data-driven one-pass approach for extracting fuzzy rules and membership functions from data to learn a fuzzy controller that will model the user' s behaviors. The intelligent learning mechanism used would learn and predict the needs of the user and automatically adjust the agent controller. They performed experiments on the Essex intelligent Dormitory (iDorm)[24] during a stay of five consecutive days. [25] designed and implemented an intelligent home environment made-up of intelligent appliance agents performing distributed and adaptive "transparent" fuzzy control. The agents interact and coordinate their activities using the Fuzzy Mark-up Language. [26] proposed a fuzzy logic system for recognizing activities in home environment using a set of sensors. Their approach allows to recognize several Activities of Daily Living (ADLs) for Ubiquitous Healthcare. [27] Used a context sensitive and proactive fuzzy control system for controlling the home environment. Their implementation consists of a lighting control system that is implemented into a smart home which learn its rule table without any predefined information and didn't need any training prior to use. Inhabitants' actions would have to be monitored, and system would have to learn through these observations. The learning process would need to be continuous, because our habits and routines change over time. The used fuzzy values are: time, outdoor light and person activity (present, absent). [28] proposed an Energy Management System (EMS) which tries to find effective and efficient energy consumption. It has two parts, the first one is a fuzzy system which its inputs can be external events like price signal, environment condition data and renewable resources or can be human behavior and preferences. This part has some fuzzy rules along with their membership functions which makes appropriate output for the second part which is an intelligent lookup table. [29] presented an approach to automated light control using fuzzy logic rules. Their system controls the number of lamplights as for the number of people inside room. [30] developed a fuzzy controller for HVAC (Heating, Ventilating and Air Conditioning) systems which maintain comfort conditions in a living environment based on the standard predicted mean vote (PMV) index. Their system takes into account the outdoor weather conditions as well as the time response of the system. [31] demonstrated that a fuzzy logic approach is able to optimize the level of energy performance and comfort taking advantage of solar energy and BAS (Building automation systems) in an office space developed a virtual model of a smart office room (SOR), equipped with dynamic shading, lighting and air conditioning control system. [32] proposed an adaptive fuzzy mechanism for heating control in smart houses. The fuzzy system is connected with an expert system and considers various input data which can enter the system. The proposed adaptive mechanism adjusts the thermal comfort rate based on the input data and IF-THEN rules.

Most of previous works were oriented to energy saving and few of them were oriented to the real comfort of users. There are few works that apply adaptation to the full set of appliances inside a smart space which make their approach lose synchronization and harmony between appliances. The most remarkable drawback of previous works is that they do not deal in depth with context-awareness which is a basic element for the intelligence of considered spaces.

3. Context Recognition in a Smart Office

3.1. Smart office description

Employees spend a considerable amount of time working in their offices. The general objective of research on smart office is to fulfill the office employee's requirements for comfort while reducing energy which enables them to work in a more efficient way. C. Le Gal [33] defined a smart office as an environment that is able to help its inhabitants to perform everyday tasks by automating some of them and making the communication between user and machine simpler and effective. Marsa-Maestre et al. [34,35] defined smart offices as an environment that is able to adapt itself to the user needs, release the users from routine tasks they should perform, to change the environment to suit to their preferences and to access services available at each moment by customized interfaces.

An exemplary office contains a set of basic appliances and furniture. The principal furniture are a desk and a chair for the office employee. Appliances could be a cooler, a heater, a set of light bulbs and a window blinds. The whole set of equipment could be classified into two categories: a) light system composed of window blinds and light bulbs, b) climate system composed of the cooler and the heater. All this equipment should provide a set of services through different forms (or modes) to the worker occupying the office. These services should be triggered according to the current context collected from different sensors installed in the office. (Figure. 1).

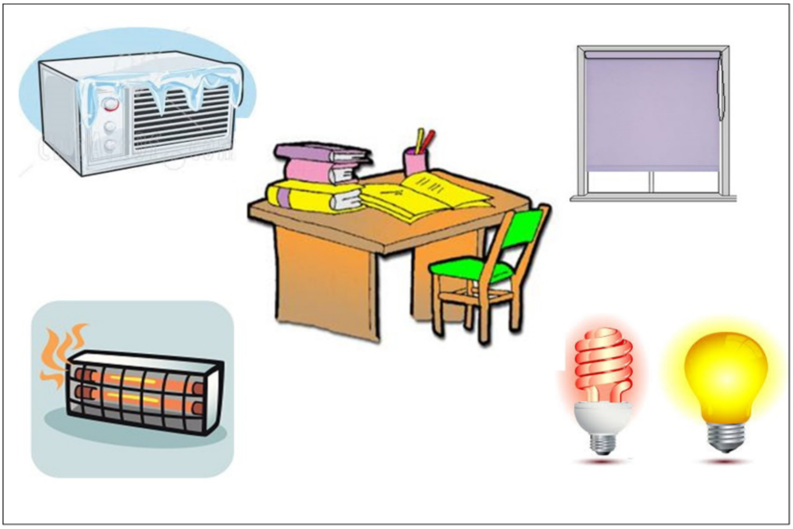


Figure 1. Components of a typical office

3.2. Context definition and extraction

Context-awareness could considerably improve the ease of use of a smart space appliances and devices without imposing undue technological complexity, effort, or inconvenience which reduces user's supervision of smart space facility control and management. A clear and complete definition of context is the cornerstone of a context-aware systems. A clear and complete definition of context is the cornerstone of a context-aware systems. So far, there is no common understanding what 'context' exactly means. Several definitions of context have been proposed since the 1990's, some of them were based on enumerating contextual information (localization, nearby people, time, date, etc.) like those proposed by [36-41]. Chen and Kotz [42] showed that general context definitions remain vague and inadequate in a computing environment. Other definitions were based on providing more formal definitions to abstract the term, like those proposed by [43, 44]. They were very general and do not help to limit the set of contextual information. In addition, most of proposed definitions were specific to a particular domain, such as human-computer interaction and localization systems. Ameyed et al [45] proposed a prediction-oriented definition of context which promotes three axes: 1) Time, 2) Space, and 3) Purpose (finality) of its use as follows: "Any entity undergoing a spatiotemporal variation and that may lead to a change in the service or the quality of service in the short or long term". In our previous work [46, 47, 48], have made a survey of existing definitions of context and proposed a service-oriented definition of context for a pervasive and ubiquitous computing environment as follows: "Any information that triggers a service or changes the quality (form or mode) of a service if its value changes.". We strongly believe that our definition is sufficiently abstract and helps to limit the set of contextual information. Based on our previous definition of context, the process of context elements extraction starts (first step) by specifying for each appliance of the smart office the set of services that can be provided. In addition, for each service we should specify also the set of information which their change of values will trigger the service. There are two basic information which their change of value will trigger appliances services: a) employee presence or entrance to the office will trigger the light system composed of window blinds and light bulbs set and b) seated employee which will trigger the climate system composed of the cooler and the heater (Table 1).

The second step consists of specifying for each service the set of forms through which the services can be provided. We should also specify for each form of service the set of information which their change of values will change the form of a service (Table 2).

The last step consists of making the union of the two previous sets to get the final list of contextual information. This information will compose the global context and, in our case,, will be composed of the following elements with their possible values (Table 3).

Table1: Service triggers

Appliance	Service	Trigger
Window blinds	Lighting	Employee presence
Light bulbs set	Lighting	Employee presence
Cooler	Cooling	Seated employee
Heater	Heating	Seated employee

Table2: Services forms changing information

Appliance	Service	Trigger
Window blinds	Closed, mostly closed, half opened, mostly opened, totally opened	Employee presence, outdoor light, indoor light
Light bulbs set	Off, low, average, high	Employee presence, outdoor light, indoor light
Cooler	Off, very low, low, average, high, very high	Seated employee, indoor temperature
Heater	Off, very low, low, average, high, very high	Seated employee, indoor temperature

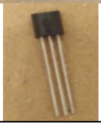
Table 3: Context elements possible values

Context element	Possible values
Employee presence	Present, absent
Seated employee	Yes, no
Indoor light	Dark, low, average, high
Outdoor light	Dark, low, average, high
Indoor temperature	Very low, low, almost low, medium, almost high, high, very high
Employee presence	Present, absent

3.3. Context acquisition

Context values are gathered using a set of sensors which are mainly from the Libelium company. It manufactures hardware and a complete software development kit (SDK) for wireless sensor network. Table 4 summarize the set of sensors used in our system by showing for each context element the sensor (s) used to gather its value.

Table4: Used sensors for context gathering

Context	Sensor	Picture
Employee presence	Libelium PIR sensor	
Seated employee	Libelium force and pressure sensor (on chair)	
Indoor and outdoor light	Libelium LDR (light dependent resistor)	
Indoor Temperature	Libelium temperature sensor	

All these sensors were embedded on a Libelium waspmote module which in turn was equipped with a Wi-Fi module to ensure communication with the controlling computer. Figure 2 shows both the waspmote and Wi-Fi modules.

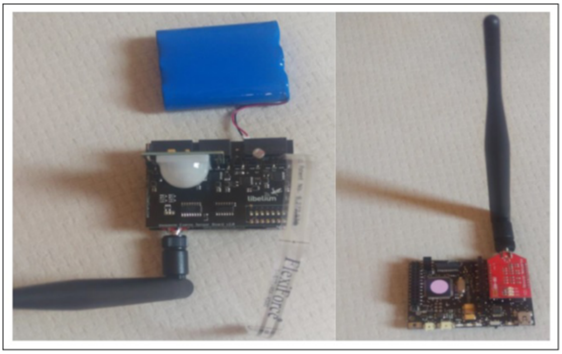


Figure 2. Sensors board and Wi-Fi module

4. Context-aware Services Adaptation

The main goal of context-aware services adaptation in a smart office is to provide the required comfort to an employee in an unobtrusive manner keeping him focusing on his main work tasks instead of losing time in setting and configuring the appliances according to the current context. For the adaptation task, we used the fuzzy logic technique. Fuzzy systems are well suited for dealing with imprecise quantities used by humans. It is often used to help make humanlike decisions. Control systems using fuzzy logic are generally fast, user friendly, cheap and they don't need much memory [49]. As mentioned before, we have two fuzzy control systems: a) light control system which responsible for adjusting the ambient light of the office and triggered when it perceives the employee presence and b) the climate control system which is triggered when it perceives the sitting of the employee. The climate system will not trigger if it does not perceive the sitting of the employee because in some cases there is no need for that if the employee makes a simple entry/exit to the office without staying there. Figure. 3 shows the two fuzzy control systems.

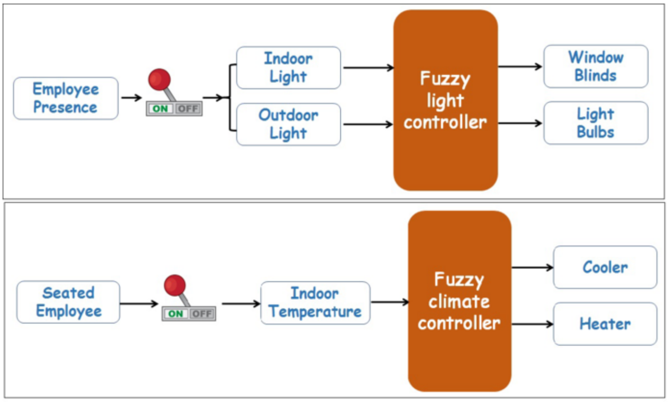


Figure 3. The two basic fuzzy control systems

The operation of the climate controller depends on only one context information namely indoor temperature and triggered when the sensor system perceives a seated employee. The set of possible fuzzy rules are as shown in Figure 4. The operation of the light controller is similar to the climate controller; however, the set of fuzzy rules is bigger and contains twenty rules. For each pair of values of indoor and outdoor light correspond a pair of values for the window blinds position and the level of luminosity of light bulbs.

For the implementation of our system, we have used the fuzzylite which is a free and open-source fuzzy logic control library [50]. Figure 5 shows the implementation of the climate controller using the fuzzylite tool. The implementation of the light controller is alike.

- *IF indoor temperature is very low THEN cooler is off AND heater is high*
- *IF indoor temperature is low THEN cooler is off AND heater is average*
- *IF indoor temperature is almost low THEN cooler is off AND heater low*
- *IF indoor temperature is very medium THEN cooler is off AND heater is off*
- *IF indoor temperature is very almost high THEN cooler is low AND heater is off*
- *IF indoor temperature is very high THEN cooler is average AND heater is off*
- *IF indoor temperature is very high THEN cooler is high AND heater is off*

Figure 4. Set of fuzzy rules for the climate system

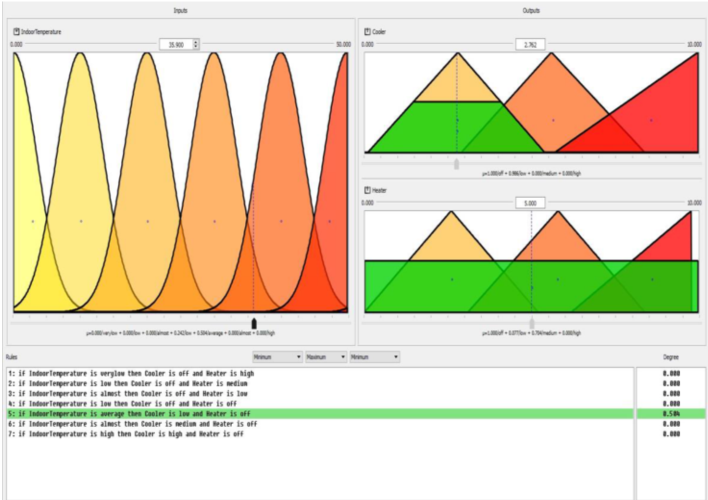


Figure 5. Implementation of the climate system using FuzzyLite tool

We have made a series of tests to evaluate our system, each Serie includes ten tests. The overall evaluation shows that the climate system has 90% of satisfactory results. We have obtained almost the same satisfaction with the light system. All the appliances of the smart office came with a remote-control device. We have used the USB-UIRT (Universal Infrared Receiver/Transmitter) which allows any USB-equipped PC to Transmit and Receive Infrared signals to common appliances of the office. To learn the infrared code of some useful button of each appliance remote control device. We have used the promixis software application (Girder) which allow us to learn different infra-red codes for each appliance remote control device. An example of Infrared code learning is shown in Figure 6.

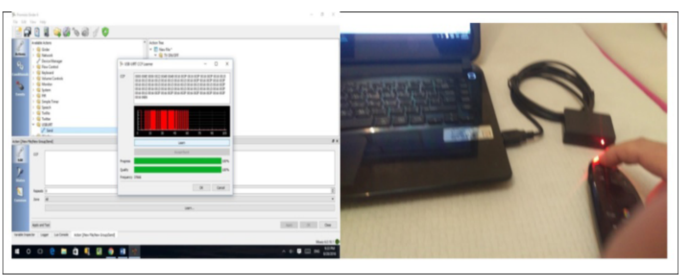


Figure 6. Learning an infra-red code of a remote-control device.

5. Conclusion and Future Work

The aim of smart spaces is to increase inhabitants comfort, help them to save energy and automating their daily interaction routines with appliances of the smart space. Automation should be done in an unobtrusive manner with minimum interaction with appliances. Office employees should work comfortably and focus on their main task not spending time in configuring appliances. Smart offices can offer these benefits for employees. Context-awareness could considerably help on the development of smart offices by making appliances providing their services automatically according the current context. In this paper, we have presented an approach for context-aware services adaption for a smart office using fuzzy logic technique. We have developed our system based on a clear definition of context and a simple and easy method for extraction context elements. We have also implemented the whole system composed of typical office appliances, network sensors for context acquisition and the command system. The evaluation of the developed system has led to satisfactory results. Our future work will focus on applying our approach on other smart spaces such as classrooms, hospital rooms, hotel rooms, etc.

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