Intelligent Systems for Smart Building Management

Tutorial Abstract

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Abstract. Managing smart buildings is a challenging task, particularly in presence of contrasting goals, such as satisfying users' needs and reducing the energy consumption. Artificial Intelligence allows to design smart buildings really capable of proactively support the users to reach their goals. Intelligent systems should be capable of exploiting the information gathered by sensors pervading the building, understanding the context, selecting the best actions to perform, and actively modifying the environment. The design of such systems is a complex task, because of the possibly wide set of functional and non-functional requirements, and the dependences among intelligent functionalities and their embodiment in the building's cyber physical space.

Keywords. Artificial intelligence, Ambient intelligence, Smart buildings, AAL, Sensors, Wireless sensor networks

1. Motivation

The design of smart buildings poses many challenges, due to the need of dealing with opposite goals, such as minimizing the energy consumption and maximizing the users' wellness, and to the necessity of guaranteeing a low level of intrusiveness. Ambient Intelligence (AmI) faces such issue by envisioning smart environments which surround users with pervasive sensors and actuators, and which apply intelligent methods to understand the environmental conditions and take the proper actions to reach system's goals [1]. In such a vision, Artificial Intelligence has a crucial role since it provides the enabling methodologies and tools for understanding the context from multiple and inaccurate data, learning users' habits and preferences, and adapting the system behavior in order to satisfy and anticipate users' needs.

2. System Architectures for Supporting Intelligent Functionalities

The design of the system architecture and its physical infrastructure, composed of sensors and actuators, strictly depends on the definition of the desired intelligent functionalities.

In [2] a reference architecture is proposed to design advanced Building Management Systems, with a particular focus on energy saving. Such architecture is composed by the following four components:

- *Sensory and Actuation Infrastructure*: represents the physical embodiment of the intelligent system in the external world and directly affects the realizable intelligent functionalities;
- *Middleware*: is responsible of dealing with the heterogeneity of physical devices, and provides the intelligent system with a unique point of access to sensory data and actuating controls, as proposed in [3];
- *Processing Engine*: implements the advanced functionalities of the AmI system; it is worth noticing that such component may be deployed according to a fully centralized approach or to a decentralized approach, depending on the specific requirements of the system;
- *User Interaction Interface*: is responsible for the interaction between the system and the end user, in order to provide him with relevant information, and to obtain implicit and explicit feedback about the user's satisfaction, as proposed in [4];

Through such components, it is possible to implement a sensing-reasoning-actuating-interacting loop, which allows the intelligent system to continuously perceive the environment and the context, reason in order to select the actions to be performed, actively modify the environment, interact with the users, and again perceive the environment to verify the effect of its own actions. The emphasis on the interaction with the user, with respect to the classical sensing-reasoning-actuating loop [5], aims to highlight its importance, not only to provide the user with relevant information, but mainly to obtain from him some feedback about the adequateness of the performed actions, in order to enable an adaptive behavior.

3. Environment and Context Sensing

The sensory infrastructure exploited by the intelligent system should include devices capable of perceiving the environmental state and the current context. It can include sensors to perceive environmental physical quantities, such as temperature, humidity, and light intensity, besides to devices devoted to measure the energy consumption, as proposed in [6]. The environmental monitoring enabled by such devices is not enough to focus system goals on users' satisfaction. On the contrary, devices capable of perceiving data related to the context (e.g. user presence or activities) are required. The presence of users or their activities may be detected by different technologies, characterized by different costs and which produce data with different accuracy levels. The designer is required to identify the best trade-off between costs and data accuracy, by considering also that dealing with noisy data involves a greater effort by intelligent modules. The sensing infrastructure can be enriched also with mobile and personal devices, especially to gather data related to the users' behavior, as in [7,8].

4. Intelligent Functionalities for Smart Buildings

The focus on energy-awareness and users' wellness introduces several functional requirements for the design of the intelligent system. Some intelligent functionalities proposed by works presented in the literature are the following:

- understanding the context (e.g., user presence, actions performed by the user);

- learning user habits;
- learning user preferences;
- planning the optimal sequence of actions which allows to reach system's goals.

4.1. Context Understanding and Learning User Habits

A smart building reacts to environmental changes by properly controlling the actuators. It is not desirable that such reactions are statically coded, but, on the contrary, they should depend on the current context conditions, that may change over time. For this reason, it is fundamental that the intelligent system is capable to extract contextual information from raw sensory data. The most relevant context information is the presence of users in the monitored premises and their activities. Such knowledge may be exploited to switch the appliances to a low consumption mode when users are absent, or to adapt the environmental conditions to their activities. One of the most popular approach is to adopt methods capable of dealing with the intrinsic uncertainty of sensory readings and with the partial correlation of such data with the considered environmental features, such as Bayesian (or Belief) Networks, as proposed in [9,10,11].

Detecting the activities performed by users allows to build predictive models of their habits. Such models represent user behavior patterns and are built by exploiting past sensory data and information explicitly provided by users.

4.2. Learning User Preferences

In order to satisfy users' needs, it is necessary to know their preferences about the environmental conditions. An ideal intelligent system should be capable to learn the mapping between users activities, current environmental conditions and the conditions preferred by users. To perform such learning process, the intelligent system can exploit both explicit and implicit feedback obtained from users [4]. The former is obtained when users voluntarily provide an evaluation of the current environmental conditions, by using an opportune system interface. The latter requires that the sensory infrastructure supports a non-intrusive user monitoring, and it is obtained by interpreting the observed interactions between users and actuators. Such feedback can be exploited to tune the system behavior; for instance, if the user interacts with actuators, his preferences are expressed by the selected settings, while if he does not perform any action, we can assume that he agrees with the system policy.

4.3. Intelligent Planning

Finally, an intelligent system should have the capability of performing intelligent planning to completely automate the building management. Such functionality requires ability to predict users' activities and the environmental changes, besides to know the effect of system actions. By exploiting such knowledge, it is possible to design intelligent mechanisms which identify the best sequence of actions to carry on in order to reach system's goals (e.g., maximize user's wellness while respecting energy constraints).

Traditional intelligent techniques adopted for planning are characterized by high computational costs; such characteristic hinders the necessity of performing prompt actions in response to environmental and context changes. Thus, the designer should find a good trade-off between long-term deliberative intelligence, capable of exploiting future predictions of the environmental state, and reactive intelligence, capable of providing fast responses to world changes.

5. Main Challenges

Most of the intelligent approaches proposed in the literature to implement intelligent systems for managing smart buildings require a training phase to learn system parameters. For example, to define a Bayesian network it is necessary to learn the conditional probability tables, or to design a fuzzy controller it is necessary to learn the set of fuzzy rules. Such knowledge, implicitly coded into the adopted model, could be known before the real deployment of the AmI system, or it could be learned after a training phase performed at runtime. In the former case, the system designer relies on the hypothesis that re-using the same knowledge in different deployments does not relevantly affect the system accuracy. In the latter case, it is necessary to adopt some semi-automated mechanisms for supporting the gathering of new data required to adapt the intelligent system to new scenarios, without excessively bothering the user. In a real scenario, facing such problem represents a great challenge because the first hypothesis is not realistic and there is a lack of robust methods that enable the self-learning at runtime.

References

[1] P. Remagnino and G.L. Foresti, Ambient Intelligence: A New Multidisciplinary Paradigm, *IEEE Transactions on System, Man, Cybernetics - Part A: Systems and Humans* **35**(1) (2005), 1–6.

[2] A. De Paola, M. Ortolani, G. Lo Re, G. Anastasi and S.K. Das, Intelligent Management Systems for Energy Efficiency in Buildings: A Survey, *ACM Computing Surveys* **47**(1) (2014), 13–11338.

[3] A. De Paola, S. Gaglio, G. Lo Re and M. Ortolani, Sensor9k : A testbed for designing and experimenting with WSN-based ambient intelligence applications, *Pervasive and Mobile Computing* **8**(3) (2012), 448–466, ISSN 1574-1192.

[4] A. De Paola, A. Farruggia, S. Gaglio, G.L. Re and M. Ortolani, Exploiting the human factor in a WSN-based system for ambient intelligence, in: *Complex, Intelligent and Software Intensive Systems, 2009. CISIS'09. International Conference on*, IEEE, 2009, pp. 748–753.

[5] D.J. Cook, J.C. Augusto and V.R. Jakkula, Ambient Intelligence: technologies, applications, and opportunities, *Pervasive and Mobile Computing* **5**(4) (2009), 277–298.

[6] F. Corucci, G. Anastasi and F. Marcelloni, A WSN-based Testbed for Energy Efficiency in Buildings, in: *Proc. of the 16th IEEE Symp. on Computers and Commun. (ISCC'11)*, 2011, pp. 990–993.

[7] F. Concone, S. Gaglio, G. Lo Re and M. Morana, Smartphone Data Analysis for Human Activity Recognition, in: *Conference of the Italian Association for Artificial Intelligence*, Springer, 2017, pp. 58–71.

[8] Y. Kwon, K. Kang and C. Bae, Unsupervised learning for human activity recognition using smartphone sensors, *Expert Systems with Applications* **41**(14) (2014), 6067–6074.

[9] A. De Paola, S. Gaglio, G. Lo Re and M. Ortolani, Multi-sensor Fusion through Adaptive Bayesian Networks, in: *AI*IA 2011: Artificial Intelligence Around Man and Beyond*, Lecture Notes in Computer Science, Vol. 6934, Springer Berlin Heidelberg, 2011, pp. 360–371.

[10] D.J. Cook, Learning Setting-Generalized Activity Models for Smart Spaces, *IEEE Intelligent Systems* **27**(1) (2010), 32–38.

[11] A. De Paola, P. Ferraro, S. Gaglio, G. Lo Re and S.K. Das, An Adaptive Bayesian System for Context-Aware Data Fusion in Smart Environments, *IEEE Trans. on Mobile Computing* **16**(6) (2017), 1502–1515.