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An indoor localization system based on artificial neural networks and particle filters applied to intelligent buildings

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A B S T R A C T

Smart Buildings aim to provide users with seamless, invisible and proactive services adapted to their preferences and needs. These services can be offered intelligently by means of considering the static and dynamical status of the building and the location of its occupants. Furthermore, gathering data about the identity and location of users enables to provide more personalized services, while wasted energy in overuse is reduced. But to cope with these objectives, it is necessary to acquire contextual information, both from users and the environment, using nonintrusive, ubiquitous and cheap technologies. In this work, we propose a low-cost and nonintrusive solution to solve the indoor localization problem focused on satisfying the requirements, in terms of accuracy in localization data, to provide customized comfort services in buildings, such as climate and lighting control, or security, with the goal of ensuring users comfort while saving energy. The proposed localization system is based on RFID (Radio-Frequency Identification) and IR (Infra-Red) data. The solution implements a Radial Basis Function Network to estimate the location of occupants, and a Particle Filter to track their next positions. This mechanism has been tested in a reference building where an automation system for collecting data and controlling devices has been setup. Results obtained from experimental assessments reveal that, despite our localization system uses a relative low number of sensors, estimated positions are really accurate considering the requirements of precision to provide user-oriented pervasive services in buildings.

1. Introduction

Over the last few years, researches on Smart Buildings have evolved in real solutions that improve the indoor life of people thanks to innovations on sensors/actuator integration and control processes, among others, but more recently, thanks to Information and Communication Technologies (ICT). Another great contributor for all these changes has been the Internet of Things (IoT) approach [1], which considers pervasive infrastructures of fixed and mobile heterogeneous nodes designed to obtain a greater integration and accessibility.

According to experts in this field, an intelligent building is one that provides people with a productive and cost-effective environment, through optimizations based on three basic elements: people (considering owners, occupants, visitors, etc); products (standing for materials, fabrication, structure, facilities, equipments and services); and processes (composed of automation, control systems, maintenance and performance evaluation) [2].

In addition, it is important to consider that buildings are one of the most critic energy consumption areas, both residential and commercial [3]. Thus, achieving energy efficiency is the cornerstone of many administrations around the world nowadays. It implies improving the interaction between building systems and users, reducing energy consumption, and therefore, CO_2 emissions.

Automation Systems are essential for these issues, as it is remarked in [4]. These systems take input data from sensors deployed in corridors and rooms (presence, light, temperature, etc) and use this information to control certain subsystems, such as heating, ventilation and air conditioning (HVAC) or security [5]. For that, an intelligent management system must provide the proper adaptability to both the environment and users, to cope with the most important comfort and energy efficiency requirements in buildings [6].

As can be noted, location plays an important role in this kind of context-aware applications, since for a vast number services provided in a smart building, it is a necessary information about the presence and location of users, and their identities could be also needed to deploy customized services. However, depending on service requirements in terms of accuracy in the location data about users, a different localization scheme could be applicable, varying the number of sensors needed and the algorithms used.

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In recent years, there has been a great technological progress on indoor localization systems, but most of the proposals do not still fully solve some problems, such as the time required in the calibration process, poor robustness or high installation and equipment costs [7].

Bearing all these aspects in mind, the work presented in this paper proposes a low-cost and nonintrusive solution for the localization data needs of the most important subsystems of a smart building, i.e. lighting and HVAC, with the goal of achieving to provide occupants with personalized and smart services in sustainable buildings. The proposed location mechanism integrates RFID (Radio-Frequency Identification) and IR (Infra-Red) data for computing user position. A Radial Basis Function Network has been developed to carry out the estimation of user locations, for that, the RSSI values are used for estimating inter-tag distance. And on the other hand, a tracking method based on a Particle Filter algorithm has been developed to infer the next positions of users. Along this paper, it can be tested how this localization system meets the accuracy, cost and complexity requirements of our indoor services, while the number of devices used by the location mechanism is optimized.

The content of this work is structured as follows: in Section 2 background information about intelligent buildings, energy efficiency and indoor positioning is reviewed. Section 3 presents the proposed indoor localization system based on artificial neural networks and particle filters. The experience deploying the system and the tests performed, as well as the analysis and discussion are shown in Section 4. And, finally, the conclusions are given in Section 5.

2. Background

As has been said, we focus the indoor localization problem on the context of intelligent buildings. Thus, given that the final purpose of our work is coming up with an intelligent and energy efficient building, our localization mechanism must meet certain requirements in terms of position data accuracy, cost, flexibility and scalability.

In the first point of this section we speak about the problem context and its location data requirements. And in the last part of this section, we review the most relevant localization technologies treated in the literature, which serve us to present our location solution.

2.1. Building management systems for energy efficiency

It is clear that to cope with most important comfort and energy efficiency requirements in buildings, an intelligent management system must be able to provide monitoring and automation capabilities [6]. In addition, in these environments, a suitable comfort level is desired for guaranteeing thermal, air quality and luminance needs of occupants. Thus, energy savings should be addressed by establishing a trade-off between comfort measures and the energy resources that are required. The aims of these systems are, first, offering a real solution to monitor energy consumption of the most important subsystems of buildings (i.e. lighting, HVAC and most energy consuming appliances); second, assess energy efficiency by computing significant parameters based on the collected monitoring data; and, third, achieving a comfort level committed to energy efficiency requirements. This last part is essential, and it is carried out by taking intelligent decisions.

During these phases it is necessary to continuously re-engineer in real time the index that measures energy efficiency to adapt the model to the building conditions. However, the optimization of these parameters comprises a complex task, full of variables and constraints. For instance, a multi-criteria decision model to evaluate the whole lifecycle of a building is presented in [8]. This problem is tackled from a multi-objective optimization viewpoint in [9], and it concludes that finding an optimal solution is unreal, an approximation of it being only feasible.

Although there are many works related to Building Management Systems (BMSs), a lot of them have failed to fully optimize energy consumption in real time, and when the BMS is not working adequately, a great amount of energy could be wasted due to excessive heating or cooling, for instance. In [10], an examination of the main issues in adaptive BMSs is carried out, however, as it is stated, there are still few works dealing with this problem completely.

The impact of the HVAC consumption in the total energy used in buildings is extremely important, comprising 50% of the building energy consumption, and in many developed countries it represents 20% of the total energy consumption [11]. The European Commission issued a recast of the Directive about Energy Performance of Buildings (2010/31/EU) [12], which pushes for the adoption of measures to improve the performance of the energy used in building appliances, lighting and, above all, HVAC systems. The CEN's standard EN 15251 [13] specifies the design criteria to be used for dimensioning the energy system in buildings and how to establish and define the main input parameters for building energy estimation and long term evaluation of the indoor environment (thermal and visual comfort, and indoor air quality). Among others, several parameters involved are location data about occupants, user activity level, total number of occupants per room, temperature, humidity and natural light. Therefore, all these variables need to be measurable and available from the automation system deployed in the building.

With this discussion it is reflected that, for making reality smart and energy efficient buildings, an important issue to solve previously is the localization problem presented inside buildings, since having in real-time information related to user location, human activity level and number of occupants results indispensable.

Besides, we must take into account the user identity data so that the intelligent system can learn and manage devices according to the behavior of users. Although solving the user identification issue in smart buildings is a key objective, privacy should be considered. Thus, some sensors cannot be installed in buildings. For instance, in Spain, video cameras could not be used in offices. These problems cause some localization systems to be unsuitable in buildings where nonintrusive, ubiquitous and cheap systems are needed. On the other hand, maintaining an updated image of the operation environment is essential for indoor localization systems.

For all these reasons, and given the context of our problem, the localization system presented here must be able to locate a user among the various areas of a building to provide optimum comfort and energy efficiency services, and thus, each user position can be calculated within the different target areas considered.

2.2. Indoor localization problem

There is a common classification of indoor localization solutions in the literature: those based on RF and those using other technologies. Among RF-based techniques we could cite those based on GPS, wireless local area network (WLAN), and RFID localization, whereas non-RF-based techniques include audio, visual, ultrasonic, infrared and laser sensors. By nature, RF signals have certain advantages over non-RF signals, as it is explained in [14], since, despite on the fact that non-RF-based localization techniques are relatively mature, they are vulnerable to environment disruptions.