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Environmental monitoring system based on an Open Source Platform and the Internet of Things for a building energy retrofit

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ABSTRACT

This paper deals with the design and development of a low cost building environmental monitoring system, and it is based on Open Source Platforms and on the Internet of Things. To achieve this aim, a wireless microcontroller with attached sensors has been used to collect the environmental data. The information obtained from the sensors is collected and stored in a flash memory card, and simultaneously is sent via WiFi to the cloud. This data is stored in an online spreadsheet, which permits us to access the information in real time.

On the other hand, a comparative analysis of the results obtained from sensors has been carried out, thanks to which several guidance guidelines have been developed for the selection of the most appropriate environmental sensor for each project. Finally, an additional evaluation of the device has been carried out through the analysis of its energy performance and providing information related to the data storage and its cost of development.

The current research shows a clear ability to develop monitoring systems for the building sector, which can also be extended to multiple applications of Smart Environments. The development of projects through these platforms will allow future research to tackle the existing barriers in monitoring campaigns.

1. Introduction

Nowadays, cities are undergoing radical operational changes. These new models known as Smart Cities aim to improve the quality of life of citizens using gathered data about the surrounding environment through the use of Information and Communications Technologies (ICT) [1]. This new situation allows citizens to be able to interact more efficiently with the new Smart elements that make up the cities, such as infrastructures, constructions and buildings (SICB). Due to its impact, this phenomenon arouses great interest both in the academic and industry areas [2].

In addition, the Internet of Things (IoT) is one of the great technologies that is supporting the Smart Cities and their SICB to achieve these objectives [3]. The optimization of traffic [4] and parking management [5], the development of water leakage detection [6] and management systems [7], the energy performance improvement of buildings [8] or appliances like a refrigerator [9] are examples of the application of this technology to different scales of the buildings and services of the cities.

Within the SICB context, buildings are one of the main consumers of energy in Europe. This sector currently accounts for 40% of total final energy consumption and therefore, its improvement can contribute to meeting the energy objectives [10]. In 2009, 68% of the used final energy in buildings has been consumed in European households. This energy consumption in homes is due to heating, cooling, hot water, cooking and appliances, however the predominant use is space heating, responsible for 70% of consumption in dwellings [11].

One-third of all residential buildings were built before 1960, and almost 84% are at least 20 years old [12]. Taking into consideration that the age of the buildings is closely related to their energy consumption, the refurbishment of the building envelope to the new standards entails a great potential for energy and CO_2 emissions savings. The annual growth rate in the residential sector is around 1% while most countries are experiencing a decrease in the rate of new building construction in the recent years, which reflects the impact of the current financial crisis on the construction sector [11]. New buildings can be built following the new high efficiency standards, however, the objective is to improve the conditions of the existing

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buildings. These represent the great majority of the building stock in which low energy efficient buildings predominate and therefore require an energy optimization.

In energy refurbishment, one of the aspects that is contemplated is the monitoring of buildings as a tool to optimize this type of interventions. The main reason, among others, is that this allows a quantitative comparison of the degree of the improvements obtained to be carried out after the refurbishment process, paying special attention to characteristic parameters such as energy consumption, interior comfort, air quality or characteristics of the thermal envelope. However, sometimes these monitoring campaigns cannot be carried out due to their excessive cost and because they require resources that exceed the capacity of most projects [13].

On the other hand, one of the research lines that is taking on great relevance is related to the trends of application of open software and hardware. One of these branches is the well-known Open Source Platforms (OSP), which allows the development of self-developed projects, thanks to the fact that it shares knowledge with the community [14]. In addition, one of the applications in which this technology is being used is in environmental monitoring [15]. This enables studies related to the environmental behaviour of the buildings to be performed in an easier way, which in turn facilitates the decision making process.

Previous experiences of the research group in building energy monitoring [13,16,17] and the review of the state of the art [18–24] have allowed certain gaps, issues and new alternatives to be detected. Monitoring devices with limited number of measurement variables, high acquisition costs, low data storage capacity, a need to use different platforms or equipment's to perform the measurements or not being able to consult the recorded data in real time are usually some of the most common issues which are presented in the monitoring campaigns. These reasons have motivated the development of the following research with the objective to solve the existing challenges in the monitoring sector. For it and for the development of an innovative system within the Smart Cities area, the combination of above mentioned emerging tools and technologies have become essential.

The goal of this paper is to build a self-developed monitoring prototype to track the environmental conditions of the buildings and to also make it applicable to other Smart Environments. It has been based on the OSP and employs the IoT to instantaneously send the data to the cloud. This paper focuses on the design and development of the monitoring equipment and provides the suitability of its implementation in a real case study. This will test the chance of its application as a tool for monitoring in larger scale projects where price, ease of deployment, connectivity and transmission of data and the freedom in its development play a vital role.

2. Background

2.1. Building monitoring

Building monitoring is a very useful tool in multiple areas. At a domestic level, the home energy monitoring and automation can motivate the consumers to use the energy more efficiently and wisely by having the overview of their appliances [25]. However, the research is valuable for diverse purposes. The development of thermal characterization methods [17] or the use of such information as feed data for the calibration and validation of the energy simulations of buildings [26] are clear examples of other forms of monitoring use.

In the domestic sector, one of the objectives of monitoring is the reduction of energy consumption by providing information on energy matters to the user. This information, according to Darby [27], is based on three principles: the knowledge of energy use, the change of user behaviour and the understanding of the changes that have occurred in energy consumption after the interpretation of available feedback. The same author states that in the vast majority of cases, the energy consumption of homes is invisible to the user. This is why he performed an analysis of the influence of different types of feedback as learning tools on tenants' energy behaviour. It showed how the direct feedback achieved through the "providing real time meter readings" managed to achieve 5–15% energy savings compared to 0–10% obtained through indirect feedback (billing).

As Shaikh's [28] research indicates, "It is generally perceivable that energy unaware activities can also add one-third to the building's energy performance." In addition, a potential energy savings of 30% can be achieved through the use of smart automation in buildings.

In short, there is no doubt about the advantages of measurement and automation, as well as the great interest of its implementation for the energy optimization of buildings by all stakeholders (tenants, building technicians, energy managers, researchers, policy developers, etc.). However, the still unreached challenges (interoperability, security, cost, sensors development potential and lack of ICT infrastructure) [29] hinder the objectives of their effective application on a large scale [10,30,31]. That is why today we need more open tools that have mass deployment capabilities.

2.2. Internet of things

The Internet of Things (IoT) has been called the next Industrial Revolution or the next evolution of the Internet. It will impact how businesses, governments and consumers interact with the physical world through Internet-connected sensors, cameras, handheld devices, smartphones and other smart IoT devices. According to Cisco [32], the IoT is simply the point in time when more "things or objects" were connected to the Internet than people. The company points out that this point occurred between 2008 and 2009 with the exponential growth of the use of smartphones and tablets.

The main strength of the IoT idea is the high impact it will have on various aspects of everyday life and the behaviour of potential users [33]. The IoT is a technological paradigm aimed at increasing the connectivity of everyday devices. That is why in the coming years the growth and use of this type of technology will increase exponentially due to its application in multiple fields. Such is the predicted growth that, the currently estimated 6.4 billion IoT devices in use will rise to a total of 20.8 [34]–50 [32] billion by 2020.

IoT revolves around an increase in machine-to-machine (M2M) communication and wireless encompasses, integrated sensors and actuators that help users in monitoring and controlling devices remotely and efficiently [35]. In this new paradigm, smart devices will collect data, transmit information or context to each other, and process information collaboratively using cloud computing and similar technologies. Finally, either human beings will be prompted to take action, or the machines themselves will act automatically. This paradigm shift creates numerous challenges and opportunities for engineering [36].

Given the great importance that the monitoring sector is taking on, and given the growth trend of the IoT for the next years, several companies are continuously advancing in the sector [37]. In addition, the list of Internet servers [38–41] that can be used as tools for storing, visualizing and sharing data is being expanded, thus enabling it to take a further step in monitoring methodologies.

In short, the IoT is a necessary tool for many work fields and research. At the same time, the IoT combined with the OSP transforms into a powerful technology that allows the user both to develop systems and to understand and make decisions in real time about the environment that surrounds him. This aspect, as we have pointed out, has become paramount in recent times.

3. Study

Atzori et al. [33] notes that any serious contribution to the advancement of the Internet of Things, should necessarily be the result of synergetic activities conducted in different fields of knowledge. In