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Editorial

Internet of Things Systems and Applications for Smart Buildings

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Recent research advances in sensors, wireless communications, network protocols, microelectronics, cloud computing, and machine learning, among others, are driving the growth of the Internet of Things (IoT). The proliferation of IoT systems is increasingly pervasive, covering application areas such as smart grids, industrial automation, healthcare, sports/fitness, smart farming, environmental monitoring, smart cities, intelligent transportation systems, logistics, etc.

One of the main driving areas of the IoT is in the context of smart buildings and smart homes, where several applications are envisioned, such as: energy consumption reduction; energy management of smart grids, battery storage systems, electric mobility, and renewable energy sources; monitoring and control of indoor environment parameters, such air quality and thermal comfort; and structural health monitoring. In this sense, the IoT system generally comprises, among other components, a network of IoT devices interfacing with sensors and actuators that are remotely configured, monitored and controlled, manually by the users and/or through intelligent automatic algorithms, with the support of cloud computing services.

In this editorial, we provide a brief review of the application of the IoT paradigm in different research areas, with the focus on smart home and smart building scenarios.

The real-time monitoring and control of electric loads in homes using IoT technologies provides tools to reduce waste and optimize the energy consumption of buildings, enhancing their energy efficiency. In this sense, Sanchez-Sutil et al. present in [1] an example of an IoT-ready smart plug designed to measure and control the energy consumed by electrical loads in different types of buildings. The developed smart plugs monitor voltage, current, power and energy, sending this information in real-time to an IoT cloud using the LoRaWAN (Long-Range Wide-Area Network) wireless technology. The authors performed experimental tests in six households to demonstrate the performance of the proposed IoT system in terms of functionality, simplicity, reliability and cost. The authors also conducted an analysis and comparison of various types of smart plugs, encompassing both research prototypes and commercially available options.

In [2], J. Oh presents an empirical study on the implications of educating users on the use of IoT systems to reduce home energy consumption and encourage behavior changes toward energy savings and sustainability. Over a period of 15 months, home owners received training regarding smart plug devices for energy consumption monitoring and reduction, after which surveys were performed to assess parameters such as user satisfaction and frequency, and their relation with energy consumption reductions. The IoT products provided to the users were smart plugs and switches currently available on the market, with functions such as power monitoring and control, scheduling and timers, and using 5G, LTE, Wi-Fi and Bluetooth wireless network technologies.

In [3], Balakumar et al. present a demand side management (DSM) scheme integrated into an IoT system designed to schedule electrical appliances in smart homes effectively, in order to reduce the electricity tariff of the consumers and minimize the peak load. The proposed scheme encourages the consumers to utilize renewable energy sources (RESs) to generate energy that can be used for their own load and/or sold to the grid, thus reducing the grid's load. In addition, the authors propose a dynamic pricing scheme to influence the consumers to run their appliances as per the scheduled time, so that planned scheduling can be executed effectively. The IoT system is based on Modbus, a real time wired networking protocol commonly used in process automation in a wide variety of industrial applications, whereas the developed DSM scheme is based on the binary firefly optimization algorithm. Based on experimental and simulation results, the authors conclude that dynamic incentives and pricing can helps to reduce tariffs for smart home users significantly.

Noticing that photovoltaic (PV) power fluctuations due to weather changes may cause mismatches in power demand and supply, Ahn et al. proposed in [4] a PV power short-term forecast system based on IoT sensors and deep recurrent neural networks (RNNs) designed to increase the efficiency and reliability of the power grid operation. The authors investigated various parameters of the proposed forecast model combined with weather parameters to optimize the model. Experimental results show that the proposed short-term forecast algorithm achieves higher prediction accuracy compared with other models.

Hossain et al. applied in [5] the IoT paradigm in the context of a building energy management system, with the goal of improving the environmental performance of buildings, as well as to enhance the learning experience on energy and sustainability. The evaluation scenario was an educational building in a London university campus. Multiple types of IoT sensor devices were deployed within three floors of the building for continuous real-time monitoring of ambient air temperature, relative humidity, illuminance, carbon dioxide and sound levels. Educational workshops using IoT sensor devices and portable Bluetooth sensors, providing real-time data visualization, were also performed to increase the students' awareness of the effects of environmental and behavioral changes on energy consumption savings, where feedback from the students was collected using online questionnaires.

Another application area of IoT systems is on improving the thermal comfort of buildings. In [6], Tanasiev et al. explore the use of IoT systems to connect devices and equipment to monitor and control heating, ventilation and air conditioning (HVAC) systems in a real case scenario. The proposed solution uses the MQTT (Message Queuing Telemetry Transport) application layer protocol and RESTful APIs as the underlying communication layers for data exchange. At software level, the integration was achieved using the Node-RED programming tool to interconnect multiple flows of data and applications. The authors refer the simplicity of integrating various devices, the reduction of the debugging and deploying time, as well as the flexibility and ease of replicating the system in other application areas, as some advantages of the proposed solution. The developed system was tested using a proportional integral derivative (PID) controller and a local programmable logic controller (PLC).

Chiesa et al. [7] present an IoT system for real-time monitoring of ambient parameters in buildings, including air velocity and mean radiant temperature, and the calculation of the thermal comfort indicators, namely the predicted mean vote (PMV) and the predicted percentage of dissatisfied (PPD). The system was designed to use low-cost IoT devices and includes a mobile application, which was developed for data visualization and end-user feedback collection. Based on experimental tests in real environmental conditions, the authors discuss the system limitations and propose improvements to increase the number of connected devices, the robustness of the IoT system against data loss or sensor faults, and the number of comfort models and parameters.

In [8], Calvo et al. propose an IoT system based on low-cost open-source hardware/software, and on a scalable IoT architecture with edge, fog and cloud layers. This system was designed for monitoring the indoor environmental quality (IEQ) parameters in buildings with the following main goals: to ensure that temperature and humidity conditions are adequate, to introduce actions to reduce energy consumption, and to guarantee the air quality. A prototype of the IoT system was built and deployed at the university building using the existing Wi-Fi infrastructure, and a smart sensor node was designed to measure temperature, humidity, equivalent CO_2 and volatile organic compounds (VOC).

The ability to monitor the integrity of a wide variety of civil structures in a continuous and fine-grained way using low-cost technologies is essential both from an economic and from a life-saving standpoint. In the last paper covered by this editorial [9], Di Nuzzo et al. propose an IoT system applied to structural health monitoring in buildings. The design of its wireless sensor node is based on low-cost MEMS accelerometers and employs the NB-IoT protocol to provide low-power, long-range communication with a server via 4G networks. Through experimental performance evaluation tests, the authors achieved a lifetime of more than ten years with a 17,000 mAh battery and, alternatively, unlimited lifetime with energy harvested from a small solar panel. Compared to a high-precision measurement instrument, results show a difference of less than 0.08% in the accuracy of estimating the modal vibration frequencies, with a cost reduction of around ten times.

In conclusion, the range of potential applications of IoT systems in the context of smart homes and smart buildings is vast, offering advantages such as enhanced energy efficiency and sustainability, improved occupant comfort and safety, and predictive maintenance. Nevertheless, some criticalities and drawbacks are associated with the deployment of IoT systems, not only in this context, but also in other application areas. IoT systems collect large amounts of data, which can be vulnerable to security breaches, raising data privacy and safety concerns. IoT devices and software are often developed by different vendors and may use different protocols and standards, leading to interoperability issues. While wireless sensor nodes eliminate the costs associated with cable installation and maintenance, the current cost of IoT devices and systems may limit their adoption, although costs are expected to decrease as the technology evolves. Finally, the technical expertise required to install, maintain and use IoT systems may delay their adoption. All these issues should be considered for the successful deployment of IoT systems.

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