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A Real Time Cyber-Physical System for Environmental Monitoring

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Abstract:

This paper presents the development of a cyber physical system that monitors the environmental conditions or the ambient conditions in indoor spaces at remote locations. The communication between the system's components is performed using the existent wireless infrastructure based on the IEEE 802.11 b/g standards. The resulted solution provides the possibility of logging measurements from locations all over the world and of visualizing and analyzing the gathered data from any device connected to the Internet. This work encompasses the complete solution, a cyber-physical system, starting from the physical level, consisting of sensors and the communication protocol, and reaching data management and storage at the cyber level. The experimental results show that the proposed system represents a viable and straightforward solution for environmental and ambient monitoring applications.

INTRODUCTION:

THE IMPORTANCE of environmental monitoring is undoubted in our age. This is the field where wireless sensor networks (WSNs) have been first used, their primary purpose consisting in the observation of the physical world and the recording of physical quantities characterizing it [1]. WSNs are large networks of resource-constrained sensors with processing and wireless communication capabilities, which implement different application objectives within a specific sensing field. They can also be used for ambient monitoring, a topic of great interest nowadays as well, indoor air quality representing an important factor affecting the comfort, health, and safety of building occupants [2], [3]. Finally, the use of wireless ambient sensors can lead to more energy-efficient buildings [4].

The constant attempts of social and economic bodies for the development of technologies for improving energy efficiency and reducing pollution and for the more efficient use of national infrastructure along with the needs of decreasing the cost of computation, networking, and sensing had lead to the emergence of a new generation of digital systems, called cyber-physical systems (CPSs), less than a decade ago. These include embedded systems, sensor networks, actuators, coordination and management processes, and services to capture physical data and to act on the physical environment, all integrated under an intelligent decision system. In this context, wireless sensors can be used to collect physical information that is further exploited by CPSs. This will lead to CPSs composed of interconnected clusters of processing elements and large-scale wired and wireless networks of sensors and actuators gathering data about and acting upon the environment.

These newly appeared systems have a lot of similarities with the Internet of Things (IoT), an enabler of ubiquitous sensing, that envisions a world in which many billions of Internet-connected objects or things, with sensing, communication, computing, and potentially actuating capabilities, will coexist, allowing an uninterrupted connection between people and things [9]. This paper presents a system for environmental and ambient parameter monitoring using low-power wireless sensors connected to the Internet, which send their measurements to a central server using the IEEE 802.11 b/g standards. Finally, data from all over the world, stored on the base station, can be remotely visualized from every device connected to the Internet. This overcomes the problem of system integration and interoperability, providing a well-defined architecture that simplifies the transmission of data from sensors with different measurement capabilities and increases supervisory efficiency. Until recently, Wi-Fi technology has not been considered for implementing wireless sensing solutions because of its inability to meet the challenges in these types of systems, with the major drawback consisting in the unsatisfactory energy consumption. However, this has changed, since new power-efficient Wi-Fi devices have been developed and new solutions can benefit from several advantages offered by this technology, namely, the reduction of infrastructure costs while improving total ownership costs, native IP-network compatibility, and the existence of familiar protocols and management tools [11]. Furthermore, high transmission rates, which are required in industrial applications, are achievable and the access to the network in this case is easy and no special wireless adapters are required [12].

The rest of this paper is structured as follows. The next section presents the context of the present work, while Section III talks about the current trends and also the motivation of using wireless sensors in the context of CPSs and of the IoT. Section IV gives a description of the developed CPS, with its two main components, the Wi-Fi sensors and the data-center. The general structure of the system and the main characteristics of the two types of devices are presented here. Section V presents the experimental results of the proposed system, highlighting the performances characteristics in terms of reliability influenced by package losses. Finally, Section VI gives the concluding remarks and the directions for future work.

Wireless Sensors in Cyber-Physical Systems:

The advances in embedded systems and information communication technologies had led to the development of sensors, which are continuously getting more powerful, smaller, and cheaper. These offer a range of advances over traditional wired sensor applications, the most important consisting in the cost reduction and simplification of deployment through the elimination of wires.

All the aforementioned facts encourage the adoption of wireless sensor networks at a scale never encountered before and it is expected that in the future, this trend will not only continue but also become even more accentuated. Furthermore, the development of CPSs brought new demands and opportunities for the use of WSNs, the combination of advanced sensing, measurement and process control having applicability across a wide range of domains, such as transportation, energy, civil infrastructure, environmental monitoring, defense, smart buildings, manufacturing and production, and others. There is no single well-established definition for the term CPSs in the literature, but almost all of the descriptions given start from the fact that these systems represent the intersection between computations and physical processes, and not their union.

A complex definition of CPSs was given by S. Shankar Sastry who states that a CPS integrates computing, communication, and storage capabilities with monitoring and/or control of entities in the physical world, and must do so dependably, safety, securely, efficiently, and in real time. In addition, CPSs can be defined as follows: CPSs refer to Information and Communications Technology (ICT) systems (sensing, actuating, computing, communication, and others) embedded in physical objects, interconnected including through Internet, and providing citizens and businesses with a wide range of innovative applications and services.

All of the definitions in the literature emphasize a strong relationship between computational (cybernetic) and physical resources in order to exceed the nowadays ICT systems in terms of autonomy, efficiency, functionality, adaptability, dependability, and usability. According to these statements, the system presented in this paper represents a CPS that employs wireless sensors for gathering and presenting data about the environment The connection between the components in large-scale systems leads to the IoT, a concept similar to CPSs, which represents a new step in the evolution of the Internet.

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The IoT is defined as a vision that allows people and things to be connected anytime, anyplace, with anything and anyone, ideally using any path/network and any service. This represents a major domain that relies on sensor networks, their presence being essential here, where they can collect surrounding context and environment information. In this case, the data generated by sensors are sent to sink nodes and, finally, reaches the cloud, where they will be Stored, shared, and processed accordingly to its relevance. Besides the advantages brought by this novel use of wireless sensors connected directly to the Internet, a set of challenges that have to be addressed, such as security and privacy, the management of huge amounts of data, quality of service, network configuration, and others, emerge.

SYSTEM ARCHITECTURE:

A. General Overview:

A graphical representation of the entire CPS used for monitoring the environment in indoor or outdoor spaces, where IEEE 802.11 b/g network coverage exists, is presented in Fig. 1. The two main system components consist of the following. 1) Wi-Fi Sensors: Low-power wireless sensors based on the programmable system-on-chip 3 (PSoC 3) device and on the RN-131C/G wireless local area network (WLAN) module. 2) IoT Platform: A BeagleBone Black embedded computer running the server application. The detailed description of the hardware and software of the two system components will be given in the remainder of the section.

B. Wi-Fi Sensors:

1) Node Architecture: The Wi-Fi sensors are represented by low-power multifunctional devices, having the three basic capabilities encountered in wireless sensor nodes, which consist in sensing, data processing, and communication. Several models of the Wi-Fi sensors were developed, employing the RN-131C/G WLAN module, using two main architectures: one in which the Wi-Fi module is used at its full potential (Fig. 2), being the central part of the node, and the other one in which an external processor is used for controlling the RN-131C/G component through serial commands sent over Universal Asynchronous Receiver/Transmitter (UART) (Fig. 3).

Fig. 1. CPS for environmental monitoring.

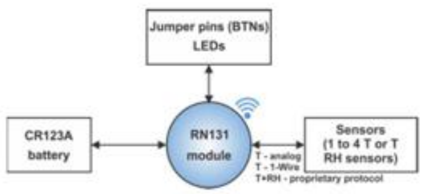

Fig. 2. Wi-Fi sensor hardware architecture the first model.

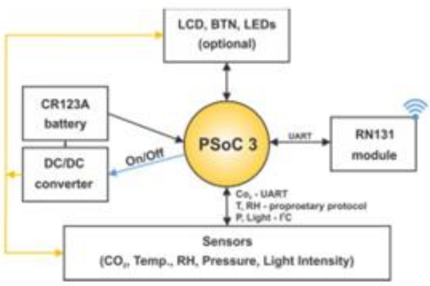

Fig. 3. Wi-Fi sensor hardware architecture the second model

The embedded application stack of the devices using the architecture in Fig. 2 is implemented on the Wi-Fi chip and uses the Embedded Configurable Operating System (eCos) operating system and the services provided by the software development kit for specifying the measurement and communication actions. The sensors that can be attached to the node measure the temperature (analog—PT1000 and digital— DS18B20 [30]) or temperature and relative

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humidity (DHT22). While the PT1000 sensor is read through an analog input, the protocols implemented by the WLAN module for communicating with the digital sensors are 1-Wire for the DS18B20 sensor and a proprietary protocol for the DHT22 sensor. The measurement application running on the node starts at predefined time intervals, performs the measurements, sends the recordings, and goes back to sleep for minimizing the power consumption. Depending on the sensor attached to the device, different ranges for the temperatures are available. The use of the WLAN module as the central processing component of the node reduced the communication latency and costs for the node, but the need of adding other sensors communicating on different protocols lead to the development of a second architecture, which is presented in Fig. 3.

Conclusion:

The development of a CPS, which monitors environmental parameters based on the existent IEEE 802.11 infrastructure, was presented. It employs sensors measuring the ambient or the environment, which send messages to an IoT platform using UDP. The communication protocol and the design of the nodes help in achieving low power consumption, offering battery lifetimes of several years. The system eliminates bulky solutions, provides the possibility of logging data where Wi-Fi network coverage exists, and can be used in a wide range of monitoring applications. Future work intends to enhance the reliability and security of the proposed system.

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