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Exploring the use of wireless sensor networks in building management

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Abstract

Due to the raising awareness of sustainability, energy efficient buildings have received significant attention by the academia and industry. Current practice of energy monitoring and control mainly relies on wired sensors, which are expensive and difficult to maintain. Moreover, systems servicing buildings do not "talk to each other", which creates silos of information resulting in inefficient Building Management (BM) practices.

The paper proposes a system framework for implementing Wireless Sensor Networks (WSNs) in building energy control and BM. WSN is an emerging technology that uses scattered sensor nodes that can sense, compute and communicate. The proposed WSNs system framework aims to integrate the required BM data into WSN for automating real-time on-site data access and processing, in which the WSN becomes an information service provider to BM applications and personnel. A web enabled central platform is proposed to process and distribute the data, and to integrate other Building Management Systems (BMS). With its application, we expect not only to continuously monitor the energy use in buildings, but also to facilitate BM functions via the distributed databases and integrated BMS.

Keywords: WSNs, energy control and management, building management

1 Introduction

The importance of energy efficient buildings has assumed great urgency due to fast depleting energy resources, energy scarcity and increasing environmental pollution (Chaturvedi, 2008). In the United States, buildings account for 72% of electricity consumption, 39% of energy use, and 38% of all carbon dioxide (CO_2) emissions (USGBC, 2009). Improving the energy efficiency in the built environment can make significant contributions to a sustainable economy (Clarke et al., 2008), which is currently under close investigation in both the academia and industry.

Recent developments in information technology have shed light on potential solutions to this challenge. The Wireless Sensor Networks (WSNs) technology is one of the promising information technologies developed in the last decades, and it has the potential to be used in improving buildings' energy efficiency. WSNs are small, non-intrusive and configurable sensor platforms that can operate for significant lengths of time on low energy supplies, and automatically configure themselves to form a data reporting network on deployment (Malatras et al., 2008). Through this network, collected wireless sensor data can be transmitted to users in real-time and on a continuous basis.

Since its development for military applications (Romer and Mattern, 2004), WSNs have been widely used in a variety of fields, such as bio-medical (Lin et al., 2006), remote medical care (Lee et al., 2006), and environment monitoring (Suhonen et al., 2006). In Building Management (BM) area, WSNs can play an important role in energy management by continuously and seamlessly monitoring the building energy use, which lays the foundation of energy efficiency in buildings. WSNs can also benefit BM practices in a variety of other ways. For example, status of major building components can be monitored by analyzing the sensor data; Instant information access on jobsites can be obtained by taking advantage of on-board data storage capacity of WSNs devices; Various BM systems, currently used for automating different tasks, can be integrated to achieve higher management efficiency by making better use of a web enabled central platform (Wang et al. 2009; Jang et al. 2008). This paper proposes a WSNs system framework for various BM uses, and outlines the future research areas for successful applications of WSNs in BM.

2 WSNs technology

A WSN consists of two types of devices, namely *sensor nodes* and *gateways*. A typical wireless *sensor node* is made up of five components, i.e. a microprocessor, a sensor board, a radio board, power source, and peripherals. The microprocessor is a core component, which coordinates all the functions of the node, and performs node level data processing tasks such as averaging over time and threshold based alarming (Malatras et al., 2008). The sensor board, controlled by the microprocessor, contains different sensors that monitor a variety of environmental factors such as temperature, humidity, sound, vibration, pressure, pollutants and motion. The radio board is a crucial component that links all the nodes together to form an integrated network. It usually complies with certain standards such as the IEEE 802.15.4 (Gutierrez, 2004). Power source is usually in the form of batteries. Reducing and optimizing the power consumption has been a key issue in node design, as it is often labor intensive or even not possible to replace the batteries (Osterlind et al., 2007). The peripherals, which are optional and variable, add a number of customized functions to extend the capability of the node. One example is additional on-board storage capacity that allows the node to store the sensor data for on-site and instant data access.

The *gateway*, on the other hand, acts like a bridge that connects a WSN to external systems and applications. The gate coordinates the nodes and distributes external orders throughout the network to perform any required task. When the task is completed, the gateway gathers the data collected by sensor nodes, and prepares it for out-of-network retrieval and analysis.

WSNs have significant advantages over the wired sensor networks, which are widely used in energy monitoring and management practices. These are:

- Cost efficiency. Estimates for the cost to run signal wire range from \$2.20 per meter for new construction to \$7.19 per meter for existing construction (Kintner-Meyer 2005; Kintner-Meyer and Brambley 2002), which can be eliminated by deploying wireless sensor nodes instead. The cost of a wireless sensor node is variable, ranging from hundreds of dollars to a few pennies, depending on the size of the sensor network and the complexity required of individual sensor nodes (Romer and Mattern, 2004), and the cost is expected to drop as the growing market leads to mass production (Kintner-Meyer, 2005). A node powered by 2 AA batteries can last for up to three years (Yu et al., 2006), and can continue to work after replacement of the batteries.
- Ease of deployment and removal. WSNs allow for temporary deployment and require no wiring or construction work, which is valuable for tasks such as diagnosis of existing problems. In additional, when the WSNs are no longer required, they could easily be removed and reused in another location.
- Variety in sensing and extended capabilities. WSNs could be equipped with various sensors including but not limited to pressure, temperature, lighting, humidity, velocity, vibration, motion,

flow, position, and so on. Moreover, the variety of peripherals enables WSNs to integrate additional functions such as on-board data storage capacity.

- Robustness. WSNs could be used in remote locations such as ceilings, in harsh environment, where the wire cannot survive or be maintained such as the nuclear power plants, and in hazardous situations, for example the fires. The autonomous nodes are also able to self-organize and self-heal the sensor network should any internal error occur. This provides considerable flexibility, reliability and convenience in BM.

3 Application of WSNs in BM

3.1 Current Use of WSNs in BM

A number of research projects have discussed the use of WSNs for BM. Osterlind et al. (2007) tested and confirmed the feasibility of integrating WSNs with building automation systems, and concluded that such integration would lead to cost savings in BM. Kintner-Meyer (2005) installed wireless temperature sensors in two office buildings for energy monitoring and control. The author argued the technical and economic feasibilities of using wireless sensors, and reported considerable operational and energy benefits. Huang et al. (2008b) reported an integrated deployment tool for ZigBee-based WSNs, and tested it in an office building. Jang et al. (2008) used WSNs for data acquisition in a web-based building environmental monitoring system. Data acquired by wireless sensors is processed and stored by a computer, and then reviewed by users via a web-based interface.

The application of WSNs has been extended beyond environmental monitoring to building automation. Feng et al. (2008) proposed a WSNs-based smart sensing and control algorithm, which could adjust the thermal quality of the built environments according to the interior and exterior temperature and the behaviour of the inhabitants. Huang et al. (2008a) designed a hierarchical WSN, which included three kinds of nodes for different levels of tasks. The WSN was tested for smart home application to automate the lighting and HVAC controls. Malatras et al. (2008) proposed an architectural framework that enabled the integration of WSNs in an overall facility management enterprise architecture, which aimed to support the building automation under a unifying framework.

To further explore the value of WSNs technology in BM, an effective integration of WSNs and Building Management Systems (BMS) is essential, which makes WSN an information service provider for automated control and management processes, and provides the BM personnel with a single access point to various systems. Moreover, the potential benefits of the additional on-board data storage capacity of sensor nodes have not been explored. This function can be fully incorporated into BM to improve the work efficiency.

3.2 Motivation

Although integrating sensor data for BM automation has been proposed before, the proposed WSN system framework aims to provide a single service access point that integrates the WSNs to BMS through a central platform. In addition, use of WSNs as part of a web-based environmental monitoring system is currently being researched; WSN data storage capacity still remains to be explored and developed for BM.

3.3 Proposed WSNs system framework

The proposed WSNs system framework designed for BM use consists of the following components: nodes and gateways, a web enabled central platform, and mobile devices such as Personal Digital Assistants (PDAs) or tablet Personal Computers (PCs).

The nodes are deployed in the areas of interest, with a customized collection of sensors, to collect data, such as temperature, humidity and lighting, and process it at the node level before transmission. Gateways are used to gather the data from nodes and make it available to external applications.

The web enabled central platform is an application that plays a central role in the proposed system framework by storing, retrieving, exchanging and distributing data. It interacts with WSNs, BMS, and users, via the Application Programming Interface (API) and its user interface, in such a way that the data gathered by WSNs is shared by the BMS via this platform. In addition, BMS is integrated by this proposed platform to provide the BM personnel with a uniform access via Intranet or the Internet. Mobile digital devices provide digital services such as data storage and processing, and the Internet connectivity. They allow BM personnel to access and control the WSNs on site, and connect to BMS for support.

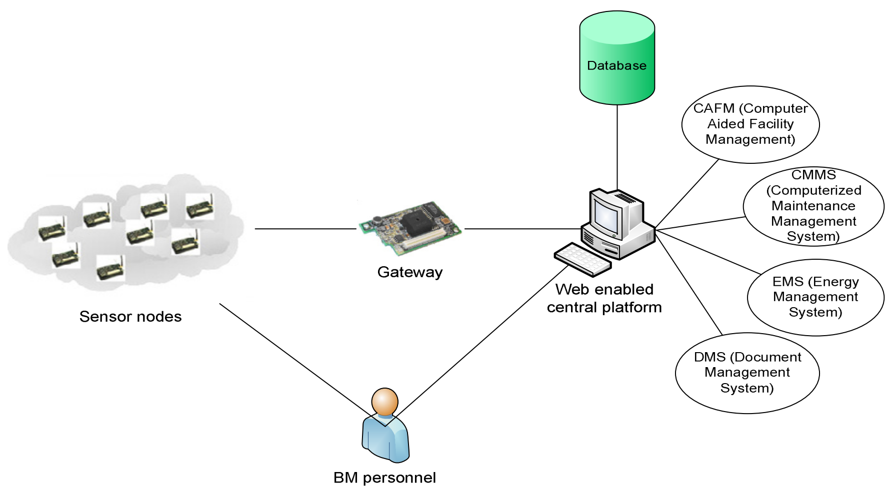

Figure 1: Proposed system framework

Information flow within the proposed WSNs system framework is as follows: deployed nodes collect raw data in various locations upon orders they receive from gateways, process the data with preloaded programs at a preliminary level, and then either store the processed data in the memory or transmit it to gateways. The gateways gather the data from nodes, and input it to certain software for further processing, or store it in a database. The central platform coordinates the database, WNSs and BMS to fulfill orders from BM personnel for building automation and control. Besides utilizing the platform, the BM personnel can also access the sensor data via PDAs or tablet PCs when they work on jobsites. With the gateway enabled mobile devices, the BM personnel can take a number of actions while interacting with the WSNs, such as creating work orders, accessing stored data, and storing data on board. They can also connect to the platform via the Internet, and work remotely.

3.4 Potential applications

The proposed system framework's rich functionality, flexibility of deployment and high affordability, especially the integration with BMS, suggest that it can be implemented for various BM functions to provide benefits in multiple ways. For example, a WSN system can play an important role in *improving the energy efficiency* in built environments by providing the following services:

- Better measurement of the in-situ performance of building systems. Although utility and power meters can measure the energy consumption over a period of time, a WSN system can provide a more detailed, and time stamped energy consumption data on a continuous basis for areas of interest, which enables the BM personnel to assess the energy use in a real-time manner with desired level of detail. Moreover, because of WSN's wireless data transmission capacity, the BM personnel can monitor and process the sorted data at their office instead of going out to the sites to take meter/wired sensor readings, which significantly increases BM efficiency.

- Provision of feedback to occupants on net energy consumption. Energy consumption data can be correlated to the sensor data to analyze the occupants' behavior in energy use. This would help the BM personnel not only to better understand occupants' energy behavior and provide them with better services, but also to make energy consumption transparent to occupants. For example, if the sensor data shows that there is no occupancy, or the daylight is sufficient in an area of interest, while the lights are on, it might trigger the necessity of occupant training to reduce energy waste and contribute to the sustainability in building operations.
- Automated energy control and management. The WSNs can export the energy use-related sensor data to Energy Management System (EMS), which is a type of BMS and integrated by the web enabled central platform. The EMS can then automate the management of energy use accordingly to optimize the energy efficiency.

To further improve the efficiency and quality of BM practices, the proposed WSNs system framework can serve as an effective solution for *preventive maintenance* by monitoring and keeping track of the status of all building components, detecting and diagnosing potential problems, and supporting mobile BM personnel with instant data access, as is described below:

- Malfunction detection. WSNs can continuously monitor a wide range of environmental variances in and around buildings, and report processed data to the BM personnel, with which the personnel can determine the status of all monitored building components and notice the malfunctions. Change alert service can be added to the system, which automatically activates a warning if the value of any variance is beyond its predefined normal range, and initializes follow-up actions by relevant BMS and BM personnel.
- Component localization. When a BM personnel is sent out to a site for regular maintenance or to execute a work order, he/she needs to know the exact location of the target component, which might not always be easily accessible or visible, especially when the component is above the ceiling, behind the wall or there are multiple components of same kind in the same location. The proposed system framework addresses this need by providing the BM personnel with access to the information stored in the node assigned to the area, which includes the list of the building components within the node's coverage as well as the components' locations and other preloaded properties.
- Real-time data access. The nodes can store necessary component-related information, such as manual, specs, schedules and maintenance records, and provide the on-site personnel with instant access to component-related information. Currently, the on-site data storage capacity of WSNs can reach 64 MB and is sometimes extendable, which is large enough to store tens of typical O & M manuals. But it is not utilized to its full capacity. Supported by the stored information, the BM personnel can perform the tasks more efficiently as they would have access to information they need for decision-making. Besides, the new information generated when executing BM tasks, such as maintenance reports, can be stored in the nodes and synced back to the relevant BMS for future use. This eliminates the need to take field notes, and transfer these notes to the BMS later in the office.
- Problem diagnosis. BM personnel need to gather data in a certain area over a short period of time to diagnose any abnormal facility performances or any construction and operational defects that waste energy, for which data loggers are currently used. Collected data need to be downloaded from the loggers and uploaded to the BM database manually and periodically, which is time consuming and error prone. With the deployment of a number of nodes, the BM personnel can obtain instant access to the required data and diagnose problems more efficiently.

4 Future research directions

The following bullet points summarize future research directions that are necessary to put these ideas into practice and realize the true value of WSNs technology in BM practices.

- Latest developments in WSNs technology should be examined thoroughly from a BM perspective. 'How improved capabilities and innovative functions of WSNs can extend the boundaries of WSN applications in BM practices' is a research question that needs further investigation.
- A testbed should be built for WSNs system framework validation and future directions for improvement. This testbed should be broad enough to apply to a wide variety of use-cases, yet they must be simple enough to provide useful metrics with minimal effort.
- The performance of WSNs should be evaluated by developing a set of measurement techniques to assess the performance (lifetime, robustness, ease of use), reliability and accuracy of a WSN system in BM for different building types, changes in building environment (interference, building materials, etc) and application requirements.
- Careful consideration should be given in order to avoid creating silos of application of specific WSNs. New applications should be interoperable, flexible and intelligent. The sensor data should be secure, and reusable.
- WSN solutions should be considered from a building lifecycle point of view from design to construction to commissioning and operations.

5 Conclusions

Though seen as a developed and powerful sensing technology, WSNs technology is still at its infancy stage regarding its applications in BM. This paper discusses the distinguished features of WSNs, such as affordability, easy deployment and maintenance, and flexibility in sensing and communication, which all make it a promising technology that can contribute to integrated and efficient BM processes. This paper also proposes a WSNs system framework for BM practices, by leveraging the basic and extended functions of WSNs, such as continuous sensing, wireless data transmission and on-board data storage capacity. The system framework also integrates WSNs with BMS to provide the BM personnel with a single point of interface to monitor, control and manage the building portfolio.

Envisioned areas of application of the proposed system framework include: monitoring of energy use in buildings, provision of feedback on net energy consumption, and automated energy control and management. It can also be applied to building malfunction detection, component localization, provision of real-time data access, and problem diagnosis.

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