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PerOMAS
Personal Office Management and Automation System

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Abstract

Nowadays, the problem of promoting sustainable energy consumption patterns has gained a lot of attention. Automation systems can improve energy efficiency, reduce costs for companies and lower their environmental impact. However, in order to be accepted by a building's occupants, a Building Automation System must not reduce the comfort nor interfere with the occupants activities. With this in mind, we propose a system to address inefficient energy consumption habits in office buildings, that can scale from an individual node in an office to a network that covers the whole building. This paper presents a summary of the current state-of-the-art in building automation, wireless communication, occupancy detection systems and the influence of the human factor in buildings' energy consumption, concepts which were used to plan our architecture. The main objective consists of building a highly flexible office management system where nodes act as environmental, presence and energy usage sensors as well as actuators, controlling the main energy consuming elements of an office, such as heating, ventilation and air conditioning, lighting and computers. Every node will work as a personal and independent office manager, striving to reduce energy usage while maintaining or increasing the comfort of the office's occupants, and also work cooperatively as a distributed platform to increase the building's energy efficiency levels. Our proposed architecture will be validated through the implementation of a prototype at IST TagusPark's campus, an academic building with office spaces for faculty and students.

Keywords:
Energy Efficiency, Building Automation System, Wireless Mesh Networks, Sensors, Occupancy Detection, Human Behavior

1. Introduction

There is a wide range of factors that incentive the rapid creation of more sustainable energy consumption patterns. These include the current financial and economic crisis, environmental pressures, including global warming, and the safety of the energy supply [1]. Unfortunately, due to various factors such as bad user habits, lack of knowledge and miss-configuration of Heating, Ventilation and Air-Conditioning (HVAC) and other systems [2], the potential building efficiency gains are not maximized. In the majority of cases, the occupants are not capable of calibrating the system to provide the best user comfort in the most energy-efficient possible manner. Also, the lack of occupancy detection

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systems in buildings can lead to high energy loses, especially in the form of supplying illumination or heating services when no one is present.

We envision a scenario where user detection systems are used for efficient lighting, shading, and HVAC management. It will also be possible for the building central heating and cooling needs to be better determined, therefore increasing the energy savings. Due to the office level granularity, the control algorithms can take into account individual user preferences. These can be determined from user feedback and interaction with the control system user interface. As such, the system can be responsible for dynamically and continuously adjusting the lighting and HVAC settings based on user feedback, making it robust in terms of user comfort, weather and environment variations.

With the constant growth of the computational power of embedded systems, it is now extremely cheap to build a device that can deal with all these problems. All the benefits of a Building Automation System (BAS) can be integrated in a cheap small device that can be installed in every room and respond to the requirements of its occupants, including resolution of conflicting preferences among several occupants of the same room.

1.1. Problem Statement

It is very difficult to adjust a BAS to provide comfort for every occupant and at the same time insure its energy efficient operation. It is also difficult to motivate people to save energy, especially in office buildings where the occupants are usually not billed for the energy they consume. Therefore, occupants are less likely to diligently set and operate HVAC and lighting systems in order to save energy.

One concrete example of these problems occurs at IST-Taguspark, a university campus with nearly two thousand students, teachers and researchers. This university is equipped with a basic BAS that has a scheduler based control that is unaware of the building occupancy levels or users' location. The scheduler is programmed to maximize energy savings, i.e. the HVAC and lighting systems work at preset time intervals during the day, with exceptions in some parts of the building. It is easily noticeable that this solution does not provide the best results in terms of energy efficiency. For e.g, during exam periods and projects deadlines, students tend to stay up until very late hours, far past the preset time intervals. In such situations, this type of system does not provide the necessary heating or cooling comfort to the occupants. This problem is more noticeable during winter and summer as these are the periods when the system is needed the most.

There are also occupant related problems that frequently happen due to negligence or bad habits such as leaving for the day and leaving the HVAC and lights on. These behaviors originate large energy loses and can be solved through user feedback analysis and automation based on occupancy detection.

1.2. Solution Proposal

This paper presents a solution for the lack of affordable personalized office management and automation systems designed to enhance the occupants comfort and minimize energy footprint at the building scale. We propose to design a system capable of controlling the building's main energy demanding equipment such as lighting, the centralized cooling system and the distributed heating system. To achieve this, the system will be composed of low-power devices distributed through strategic locations and in every office. The management of each office will be automatic and based on the user presence in the building and office. The installed devices will feature sensors for occupancy awareness and ambient conditions that will automatically calibrate HVAC and light settings for each user. On top of it, the individual data from each office will be aggregated to determine the buildings total heating, cooling and energy needs. Based on this data, relevant equipment can be adjusted to the required capacity, thus improving energy efficiency.

2. Related Work

Three of the most used BASs technologies were studied: Building Automation and Control Networking Protocol (BACnet)[3], LonWorks[4] and KNX.

What we found is that these technologies usually require a specialized installation of multiple devices that need an advanced configuration. Because of this, their configuration is usually restricted to the building managers and personalized configuration for every office is very difficult to archive using this type of systems.

In the past decade, wireless networks have gained momentum, receiving a lot of attention from the Building Automation (BA) industry and standards development organizations. The use of wireless communications reduces installation costs since wired solutions require cable trays or conduits. We studied the technologies based on Institute of Electrical and Electronics Engineers (IEEE) 802.11, 802.15.1, 802.15.4 standards and found that technologies like ZigBee[5] and 6LoWPAN[6] are mostly used for this type of applications. Their limitation is the use of the IEEE 802.15.4 standard which has a maximum data rate of 250 kb/s. Another possibility is the use of protocols based on IEEE 802.11 such as 802.11s[7] or Batman-adv[8] that also have support for multi-hop networks and offer much higher data rates of up to 1.3 Gbp/s with the new IEEE 802.11ac revision.

Occupancy detection techniques are used nowadays to reduce energy consumption in buildings by supplying lighting, HVAC and other building systems with occupancy information. We analyzed some of them such as: RFID, Passive Infrared, Vision Based, Wi-Fi and Bluetooth based.

They were compared in term of user detection, identification and detection range. Taking into account that almost every modern building is equipped with a Wi-Fi system, we can easily identify the users in a particular area[9]. Detection with more precision could be archived using multiple small range cells, based on Bluetooth[10] or RFID.

Studies have shown that the human behavior is responsible for large variations in energy consumption[11]. Consumer behavior may significantly influence the level of energy demand by choosing the temperature goals, ventilation rates and habitual actions within the office.

For example Satin *et al*[1] found that in buildings equipped with a thermostat, occupants are more aware of the interior temperature and therefore tend to turn it on more often, increasing the energy use.

3. Proposed Solution

3.1. System Requirements

Requirements need to be defined in order to choose the appropriate architecture in terms of its performance and functionality. Considering the building of IST-Taguspark as an example, the system would need to be capable of supporting nearly three hundred offices.

Another identified requirement is the ability for the system to determine office, zone and building occupancy levels. This would allow efficient lighting and HVAC control with incremental granularity.

The system must be capable of finding and maintaining multiple user preferences based on their interaction with the system, which also needs to be minimal. Each office node must allow individual remote configuration via an easily available tool such as a web browser, that is also available in a smart-phone.

Finally, it must be possible to identify the user location with medium/low precision inside the building and determine, with high certainty, if the occupant is in his office.

3.2. Survey

A survey was done to characterize the comfort preferences and habits of the users of IST-Taguspark. All data was based on the replies from 69 users. The data demonstrated that all the users have at least one mobile equipment with an average of 2.1 devices/person, 98% were equipped with Wi-Fi and 96% with Bluetooth technology. Regarding energy related user habits, 72% of all users reported to only sometimes shutting down the HVAC system when leaving the office. Likewise 43% said the same about the lighting in the office.

3.3. Architecture

To assure the scalability of the system, a hierarchical architecture, shown in Figure 1, was developed that better adapts to the required application. It follows a centralized hierarchical architecture because of the way the building services are installed, such as the HVAC system or electricity. In a building, these services always merge at distribution points where they can be measured and controlled, and as such, our model will follow a hierarchical model in order to map this structure. The proposed system consists of three main components: the assistant, the gateway and the core.

The assistant is the most important component of the system. It will be responsible for collecting data from the attached sensors and to control the HVAC and electrical systems of the office. Relevant data will be relayed to a

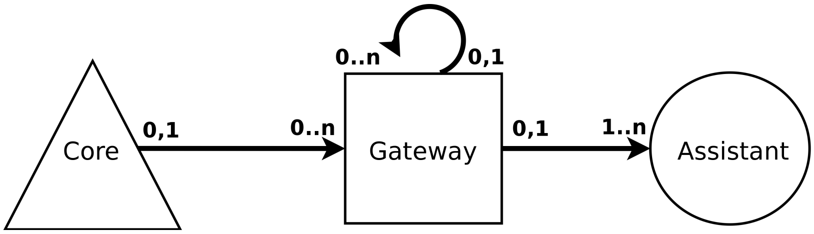

Fig. 1: Architecture of the system

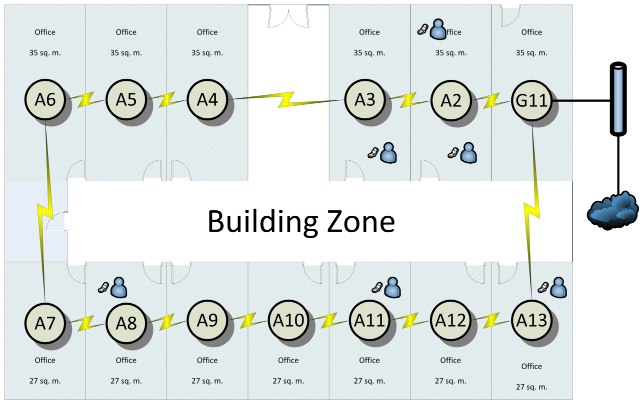

Fig. 2: An example of RF communication paths within one building zone

gateway using the publish-subscribe model. The gateway could subscribe to several parameters, then if some of these change, the assistant will immediately send the new values to the gateway.

The gateway is responsible for collecting data from some assistants, being placed in strategical zones where it can be used to trigger actions affecting several assistants, such as adjusting a common boiler or controlling the lights of a corridor common to several offices. Triggered actions could be as simple as turning on a switch or as complex as calling the nearest fire department with accurate information of the building and offices in case of a fire.

The gateway will also be responsible for storing a permanent record of the collected data. It's analysis could demonstrate usage patterns and could lead to more energy efficient configurations of the system. One of such examples is the cooling system at IST-Taguspark, which has a large inertia because the coolant is refrigerated during the night. Thus, instant values of the demand from such a system cannot be used to adjust it in real-time and need to be predicted almost one day in advance.

Depending on the building complexity, different number of hierarchical levels could be projected, following a strategical distribution such as zones, building levels or the structure of other energy demanding resources. Every gateway will also aggregate the data and only pass summary information to upper levels. This is very useful in high density buildings as it decreases the load on upper gateways. Gateways, being in smaller numbers, are expected to make use of the buildings Ethernet infrastructure.

The core has the same functions as the gateway but does not have to relay data to any other gateway. It works as the centralized, top level of the hierarchy node and could control systems common to the whole building such as a centralized HVAC system, building energy generator or the main power switch.

The presence of the gateway and core nodes is optional, as depicted in Figure 1. A gateway can connect to one or more assistants and can also connect to a higher level gateway or the core. The model enables an adaptable number of hierarchical levels in a tree like format, with the flexibility to expand from one to many nodes.

Mesh Network. The assistants' communication with the gateways will be based on a wireless mesh network. This approach speeds up the deployment of new nodes and also ensures the modular scalability of the network. For example, Figure 2 shows an approximation of the office's layout in a building zone and the possible routing paths created

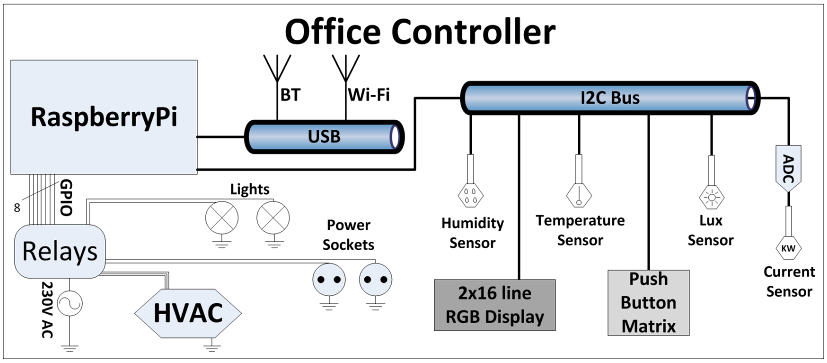

Fig. 3: Communication between the controller and the attached display, sensors, buttons, actuators and RF interfaces

between the nodes. The use of a mesh network helps to extend the network's range. Where no direct communication with the gateway is possible, messages can still be relayed by other nodes.

IEEE 802.11 (Wi-Fi) and IEEE 802.15.4 (ZigBee) are two open standards that support mesh networks. The IEEE 802.11 technology was elected because of the higher data rates archived compared to the ZigBee interface. This factor is important because the assistants will need to be capable of providing access through a web browser, for which 250 kb/s[5] is not enough considering the high density of assistants. Furthermore, due to the way the nodes are to be installed, the increase power usage of 802.11 will not be an issue.

Hardware Components. The prototype nodes will be based on the Raspberry Pi single-board computer. It was chosen mostly because it is a cheap and fast platform that runs Linux and has many I/O ports.

The collection of Input/Output (I/O) ports have support for General Purpose Input/Output (GPIO), Inter-Integrated Circuit (I2C), Serial Peripheral Interface (SPI) and Universal Serial Bus (USB) as shown in Figure 3. We will be using current sensor clamps for estimating power usage within each office. As the clamps produce an analogue output, an Analog-to-Digital Converter (ADC) with I2C interface will be used for reading the values. Our system will feature sensors capable of measuring the office ambient characteristics such as temperature, humidity, luminous intensity and energy consumption. A set of relays will take control of the lights, power sockets and HVAC system, which are the most common systems in a typical office. The display and buttons will be used for smart-phone pairing and user interaction.

User Detection. Based on the survey we decided to use the Wi-Fi infrastructure to detect the user's location inside the building since the entire campus has Wi-Fi coverage. Because of its low precision, the nodes will also be equipped with Bluetooth dongles to detect the presence of the occupants within the office. Both technologies complement each other, achieving high precision in the desired locations (office).

Office energy management. Each Assistant node will be responsible for managing the power usage of each office. It is capable of sensing temperature, humidity and luminosity, it is capable of determining if the office users are present in the office and the building, it measures energy consumption and can control the HVAC, lights and power outlets. It also interfaces with the users, locally through its screen and buttons and remotely through its web interface. When an Assistant is installed, it takes the place of the light switch and HVAC controller. The office occupants will no longer be able to directly control theses systems, but will be required to interact with the Assistant. The Assistant will control these systems using a fusion of manual user control, sensed information and historical user interaction. The goal is for each Assistant to learn from the user interaction and over time adjust to the user preferences, reducing the need for user interaction.

The Assistant is expected to reduce power consumption by implementing several strategies. Lights can be turned off when the user leaves the office. When the user enters the office and while he is there, the luminosity sensor can be used to determine the need for turning on all the lights, only some or none. Due to its higher inertia, the HVAC should not be turned off as soon as the user leaves the office, but can be turned off when it is detected that the user has left the building. Conversely, it can be turned on as soon as the user enters the building (ex. warm up the office), thus increasing his comfort. If the user permits it, power outlets can be turned off when he abandons the building, preventing standby devices from wasting energy.

The HVAC set point can be dynamically adjusted throughout the year and the day in order to minimize energy consumption and increase user comfort. The outside temperature and calendar date can be used to estimate the type of clothing being used and set the temperature accordingly, higher in the summer and lower in the winter. The time of day can be combined with weather information in order to determine sunlight incidence and define the temperature accordingly.

3.4. Results Validation

In order to validate the proposed solution and its efficiency gains, first we need to obtain usage data of the already existing system. Power usage, number of user interaction with the system and occupant comfort are some of the parameters to measure before installing the new architecture. These values will continue to be measured after PerOMAS installation, so we can evaluate its gains.

The tests will cover a set of offices in a building zone at IST-Taguspark. Some of them will contain more than one occupant, thus allowing tests with conflicting personal preferences. Other parameters such as the usefulness of the new system and its impact on occupant behavior will also be evaluated using questionnaires.

4. Conclusions

In this paper, we present a BAS solution with the objective of offering minimization of the overall energy consumption of the building, while maintaining or increasing user comfort. The solution will integrate office automation, occupancy detection, Wireless Sensor Network (WSN) and the building services. For an ubiquitous automation, occupancy detection techniques based on Wi-Fi and Bluetooth were explored. The final prototype will be based on the Raspberry Pi single-board computer and installed in a building zone at IST-Taguspark. We expect to observe an increase in user comfort as well a decrease in energy consumption and need of user interaction.

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