# A System for Energy Conservation Through Personalized Learning Mechanism

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Abstract: Several challenges exist in developing smart buildings such as the development of context aware algorithms and real-time control systems, the integration of numerous sensors to detect various parameters, integration changes in the existing electrical infrastructure, and high cost of deployment. Another major challenge is to optimize the energy usage in smart buildings without compromising the comfort level of individuals. However, the success of this task requires in depth knowledge of the individual and group behaviour inside the smart building. To solve the aforementioned challenges, we have designed and developed a Smart Personalised System for Energy Management (SPSE), a low cost context aware system integrated with personalized and collaborative learning capabilities to understand the real-time behaviour of individuals in a building for optimizing the energy usage in the building. The context aware system constitutes a wearable device and a wireless switchboard that can continuously monitor several functions such as the real-time monitoring and localization of the presence of the individual, real-time monitoring and detection of the usage of switch board and equipment, and their time of usage by each individual. Using the continuous data collected from the context aware system, personalized and group algorithms can be developed for optimizing the energy usage with minimum sensors. In this work, the context aware system was tested extensively for module performance and for complete integrated device performance. The study found the proposed system provides the opportunity to collect data necessary for developing a personalized system for smart buildings with minimum sensors.

## 1 INTRODUCTION

Resources for electrical energy are decreasing day by day, while its use is increasing day by day. Therefore, we need to reserve electrical energy for future use. About 50 million tonnes of electrical energy is wasted globally every year due to negligence and carelessness (Nationmaster 2014). Smart buildings not only conserve electrical energy, but also provide resource sustainability and more efficient and effective energy monitoring operation. A building which has context awareness and an ability to react to it is termed as smart. As a result of this power conserving nature, many countries have developed smart buildings (Eun-Kyu Lee and Gadh 2013).

Smart buildings are more effective when the personal requirement of each person in the building is studied and reacted accordingly, i.e. a personalized system in which the electric power is consumed according to the usage behaviour of the occupants. The system notes when and where the occupants enter and exit, what building space the occupants inhabit, and what time and how long they occupy that space so that the system can automatically adjust to the electrical requirements of each individual (Sinopoli, 2014). Similarly, when a group of persons enter a room, the system is designed to have optimal electricity consumption. In such a case, the group behaviour is studied and reacted according to the algorithm applied, where the algorithm supports the majority interest in the group.

In this work, we designed and developed a context aware wearable device and a wireless switchboard to monitor and track the switch on/off activities performed by each of the individuals in a building. The system was tested under three different scenarios namely, the data acquisition phase, the working phase and when a person is

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absent from the room. Whenever an individual enters a room and performs any switch on/off activity, his/her presence in the room, along with their activities, are updated to an aggregator, with the help of a wearable device and a wireless switchboard, so that if ever the same individual enters the room again, the end device can be automated for the previously used time duration. A smart phone with Near Field Communication (NFC) can provide the same functionality of a wearable device, i.e. to monitor or track the individuals within a room and to distinguish the switch on/off activity performed by each individual. However, in order to learn about the individual's behaviour, each individual must carry his smart phone anywhere within the building, especially when he/she approaches the switchboard, that in turn can become a burden to the individual. A better way to solve this issue is by replacing the smart phone by a wearable device tied to the wrist so that each time an individual raises his wrist to switch on any device, his identity is noted by the wireless switchboard.

The remaining paper is organized as follows. In section 3, an architecture for the system is explained, describing the design of each of the devices used in the system and the working of the whole system. In section 4, an algorithm for the working of the system is summarized. Finallyin section 5, the hardware development of the devices and module-wise and system-wise testings are discussed.

## 2 RELATED WORK

Currently, smart buildings feature multi-system integration with multi-functions that integrate data from different buildings to r monitor data against benchmarks or established goals. For effective management operation based on the human behavioural study, several innovative ideas are being incorporated into smart building technology (Sasidhar and Thomas, 2014). During the early days of development of smart buildings, developers aimed to provide fundamental resource services like water and electricity. Now, developers focus on providing methods to conserve more energy resources such as thermal energy.

The authors in a research publication (Sinopoli, 2014) proposed a smart learning based control system that controls the AC appliance through a Bluetooth transceiver interfaced to the controller. It uses light sensors to detect whether any windows are open before turning on the AC. Through this system, the researchers saved upto 5% of energy. However, they did not consider the end appliances other than AC. In our system, all the electrical end appliances including TVs, computers, etc are considered.

JinSungByun *et. al.* proposed an intelligent system in a building that provides energy saving services and remote control over consumer devices, consisting of a set of sensor modules like temperature sensors, humidity sensors, and light intensity sensors with an internet interface which helps to remotely control the end devices at the time of need (JinSungByun, 2011). Their system saved up to 16-24% of energy. However, they did not discuss anything about the topology of sensor networks. The system that we developed minimizes the use of sensors, thereby minimizing the cost and complexity.

Dae-Man Han *et. al.* proposed a sensor network based smart, light control system for smart home and energy control applications. For better device control and efficient energy management, smart home networking used IEEE 802.15.4 and Zigbee networks (Dae-Man Han, 2010). However, they considered only lighting system applications and did not take into account other electronic appliances like TVs. Furthermore, their system did not study the behaviour of each individual and did not explain the algorithm for controlling the end devices. Moreover, they did not find a way for the optimization of sensor use. Zigbee communication is used in our system because it provides a low cost and low power communication. As the use of numerous sensors can increase the cost and complexity of the system as in (Jin Sung Byun, 2011), the sensor usage in our system is minimized.

Boungju Jeon *et. al.* proposed a Zigbee based intelligent self-adjusting sensor (ZiSAS) that can take into account the limitations of sensor networks such as battery lifetime, bandwidth, storage capabilities etc (Boungju Jeon, 2012). It automatically configures the network topology and system parameters and detects a node failure or addition or removal of any node to the network. Their system reduced energy consumption by 8-34%. However, the authors did not state the condition when the residents in the building exhibited irregular behaviour. This makes it difficult to generate a common pattern from the same situation. Furthermore, the researchers did not explain about the routing protocols and the way sensors can be optimized.

Yuvraj Agarwal *et. al.* presented a 'presence sensor platform' that detects the presence of occupants in an office building through which the HVAC equipment can be automatically adjusted according to the context (Agarwal, 2010). The node is composed of a PIR sensor module that detects human presence and a magnetic reed switch door sensor that detects whether the door is opened/ closed. The authors did not consider a method for battery replenishment and optimization of sensor usage. Moreover, this system will require many PIR sensors to be deployed within the room for motion detection, which is not a cost effective solution. Our system is more affordable than conventional systems since it does not require the sensor installation cost and wiring cost.

Brdiczka *et. al.* proposed a system for detecting and studying the contextual human behavioural models in a building by using camera tracking systems, microphones etc (Brdiczka and Langet, 2009). Through this system, they reduced energy consumption to 10-15%. The system required full time working of the sensors for detection, which can affect the lifetime of nodes. However, the researchers could not detect the human behavioural situations other than the stated 6 situations in the paper. The use of cameras made the system expensive. Also, they could not provide privacy to rooms. So in our system, for the purpose of monitoring the position or activity of the individuals, cameras and microphones were not used.

A. Fleury*et. al.* proposed a smart home that can measure the activity of a person and help people in their activities (Fleury, 2008). The environment within a building or room was monitored using numerous sensors and microphones to detect any distress situation or the activities in the room. However, the researchers could not minimize the number of sensors used and did not explain the topology of deployment of the sensor network. Moreover, the privacy to the rooms is lost. In our system, microphones are not used for detecting the presence or activities of a person in a room as it can break the privacy of occupants.

# 3 SMART PERSONALIZED SYSTEM FOR ENERGY MANAGEMENT

The Smart Personalized System for Energy Management (SPSE) is a context aware system, designed to work in office buildings, where people inhabiting the building exhibit regular behaviour. The aim of this system is to conserve energy or optimize energy usage through context aware data collection and personalized learning mechanisms. A wearable device has the capability to communicate with a wireless switchboard to monitor and track the individuals who have performed the activity of switch on/off. The information collected by the wireless switchboard through the wearable device will be used to develop personalized learning of each of the individual's behaviour. This personalized learning will provide the opportunity to minimize energy consumption by each individual under specific time frames. The SPSE architecture is shown in Figure 1.

## 3.1 Design of Wearable Device

The wearable device was designed in such a way that it is compact and handy to use. It should contain a communication module that can convey the

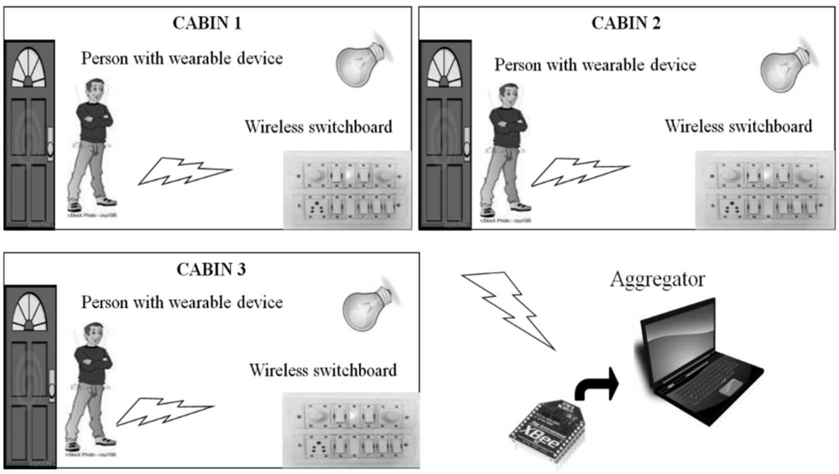


Figure 1: SPSE architecture.

presence or absence of person in a room, identify each individual and be able to distinguish the switch press of each individual among the many gathered in the room.

A Zigbee module (XBee Series 1) can help to convey the presence or absence of individuals in a room (International, 2014). Since XBee uses 3.3V, a micro-controller that uses 3.3V power supply - MSP430G2553 - is best suited to make the device more compact (Instruments, 2013) (Msp430 launchpad, 2014). An RFID tag (125KHz) is used to identify and to distinguish the switch press of each individual among the many gathered in the room. Two AA batteries of 1.5V each in series are used to power up the device. In this way, each wearable device gives a unique identity to each individual in the building.

### 3.2 Design of Wireless Switchboard

The wireless switchboard is meant to monitor the position information of the individual, detect the switch on/off activity performed by the individual, transmit the collected information to the aggregator and perform the controlling operation of end devices. It uses an active RFID reader that reads from a passive RFID tag on the wearable device to indicate that the individual is near to the switchboard. The device also uses a Zigbee module (XBee series-1) for communicating the information, a micro-controller (PIC16F877A) with a voltage sensing circuit, voltage regulators (5V and 3.3V) and an electromagnetic relay to relay the current to the end device.

### 3.3 Working of SPSE

Each individual within the building carries a wearable device that provides a unique identity. Figure 2 shows the sequence diagram for the working of the system. The Zigbee module on the wearable device continuously transmits a message to the wireless switchboard signalling the presence of the person within the room. The wireless switchboard continuously monitors the reception of this message. Whenever the message is not received beyond a threshold time, the absence of the person in the room is marked and all the end devices within that room are turned off. When a person enters the cabin, turns any switch ON and then turns off the device after his requirement, his RFID tag identity along with the information such as what switch he pressed, the time duration for the device usage is transmitted to the aggregator. The aggregator is a Zigbee module connected to a PC that stores the database of electrical use by each individual and displays the person's switch on/off activity information. This information is displayed on the serial terminal of X-CTU software. The switch on/off activity of the individuals is continuously monitored and updated to the database where a common pattern is developed for each of them. The data acquisition phase and working phase occur simultaneously. The data acquired is analysed using machine learning algorithm to develop a common pattern of electrical behaviour for each individual. The machine learning algorithm can be supervised or unsupervised learning. For supervised learning, the database of each individual's electrical usage is known a-priori, so that it becomes useful to classify the individuals from the available training set. For unsupervised learning, the electrical behaviour of each individual is necessary to cluster the individuals and develop a common pattern from them.

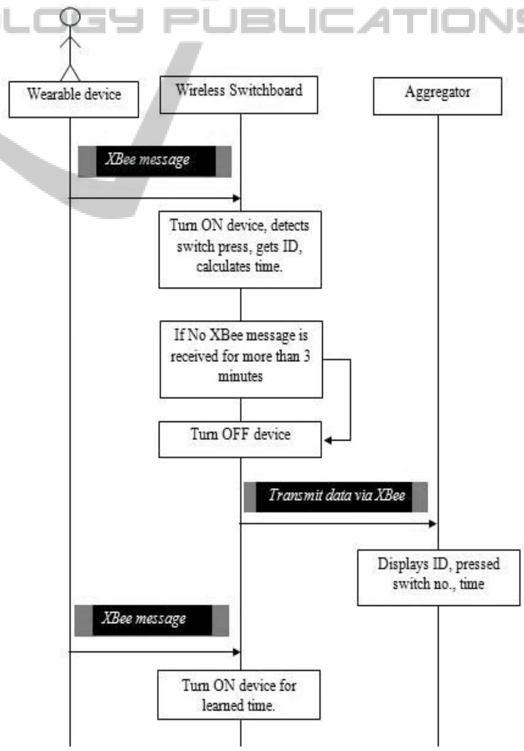


Figure 2: Sequence diagram of the working of SPSE.

## 4 ALGORITHM

### 4.1 Wearable Device

First of all, it is important to set the parameters required for the application to run properly, such as, stop the watchdog timer, set the Digital Crystal Oscillator (DCO), set the transmit (Tx) and receive (Rx) pins of UART, set the serial clock and baud rate to 9600. Then, data must be continuously transmitted to provide an identity periodically to each person for 5 seconds interval. The interval is provided by calling the delay function. The flow chat for the working of the wearable device is shown in Figure 3.

## 4.2 Wireless Switchboard

Whenever a person enters a cabin and performs any switch/off activity, read the RFID data from the tag on the wearable device. If the switch is on, turn on bulb and start a timer. If the switch is off, wait for the switch on action to be performed. Then, check whether any XBee data is received from the wearable device. If no XBee data is received for more than a threshold time, then turn off the bulb. Transmit the information such as RFID, switch number and time duration of use of the device to aggregator via XBee. In between, detect the switch off condition. If the switch is turned off, turn off the bulb and note the timer overflow value. Calculate the time for which the device was turned on. Then, transmit the information like RFID, switch number and time duration of use of the device to aggregator via XBee. If any XBee data is received again at the same time after the data has been acquired, then turn on the bulb for the previously obtained timer value, indicating the working phase of the system. The data acquisition phase and working phase occur simultaneously. The acquired data can be averaged to obtain the common working pattern for each individual. Figure 4 shows the flow chart for the working of a wireless switchboard.

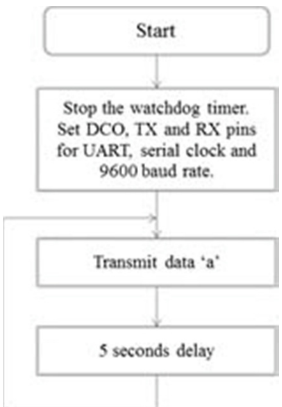


Figure 3: Flow chart of wearable device.

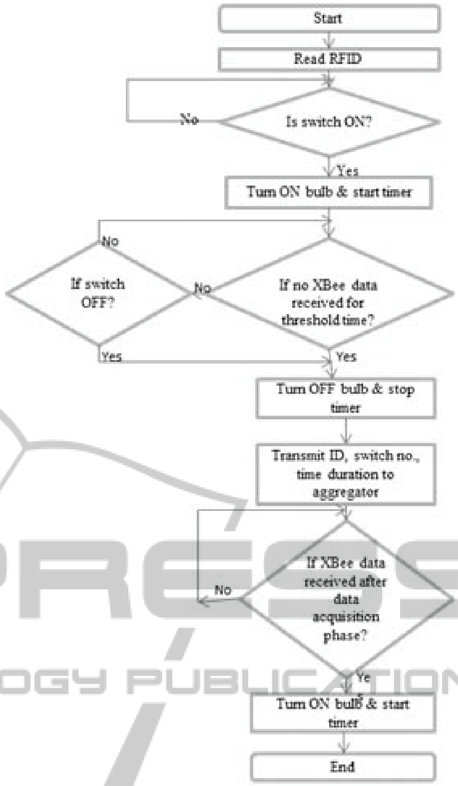


Figure 4: Flow chart of wireless switchboard.



# 5 HARDWARE IMPLEMENTATION AND TESTING

Hardware was developed for both the wearable device and the wireless switchboard. Wearable device consists of a RFID tag, Zigbee module and a micro-controller. Wireless switchboard consists of a Zigbee module, relay, bulb, switch, voltage regulators, micro-controller and a RFID reader. The hardware of both devices is shown in Figure 5 and Figure 6.

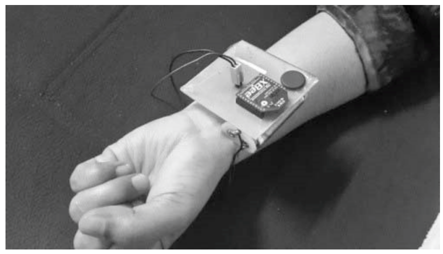

Figure 5: Hardware of wearable device.

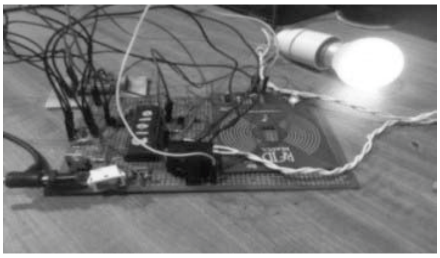

Figure 6: Hardware of wireless switchboard.

As a part of the testing, whenever a person carrying the wearable device presses the switch, the bulb is turned on. As the person approaches the switchboard, the RFID tag transmits its 12 Bytes of data to the RFID reader in the wireless switchboard, indicating the identity of the person turning on the device. The 12 Bytes of RFID data actually contains a start byte (0x0A) and a stop byte (0x0D), of which the middle 10 bytes are the original RFID data (Rhydolabz, 2014). The person turns the switch off after 40 seconds of time, which in return turns the bulb off. As soon as the bulb is turned off, a message is delivered to the PC via Zigbee (XBee S1), regarding the switch press information: "Switch-1 is pressed for 40.00 seconds duration by 720040BF9A." The X-CTU software has the serial terminal that shows this information. The circled 10 Bytes in Figure 7 are the ID values of RFID.

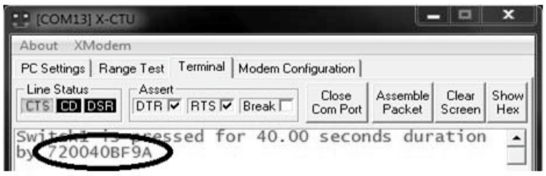


Figure 7: X-CTU terminal showing test result of the system.

The three scenarios under test are: data acquisition phase, working phase and absence of person in the room. In the data acquisition phase, as explained above, the details regarding the entry of the person, his ID, what switch he presses, for what duration are studied and updated to the aggregator. In working phase, whenever the same person enters the cabin again after the data acquisition phase, the bulb is automatically turned on for the learned amount of time (40 seconds for the above test). In case the person was not in the room for more than a threshold amount of time, the bulb is automatically turned off. The full hardware set up of the system under test is shown in Figure 8.

The average walking speed of the individual is about 5Kmph (Walking, 2015). So the minimum time the individual takes to exit the room is,

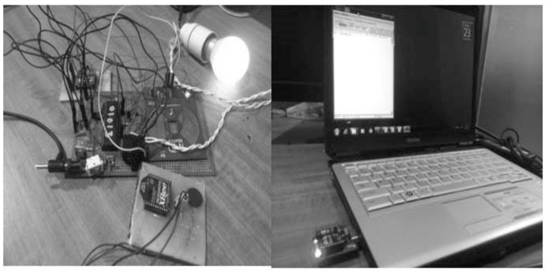

Figure 8: Hardware of complete system.

Time = Distance to the exit door ÷ Average walking speed of the person (1)

The XBee Series-1 in the wearable device can be designed to transmit messages to the wireless switchboard for a room of any dimension. The individual walks a minimum distance of the room dimension to exit the room. So, the minimum time the individual takes to walk out of the room can be found from equation (1). The received signal strength of the Zigbee message helps the wireless switchboard to estimate the distance from the wireless switchboard to the current location of the person with wearable device.

The battery replacement of wearable device depends on the power consumption of the XBee module and the microcontroller. Power consumption of wearable device at active mode,

$P_1 = 3.3 \times (45 + 0.23) \times 10^{-3} = 149.26mW.$

Power consumption of wearable device at standby mode,

$P_2 = 3.3 \times (10 + 0.5) \times 10^{-6} = 0.03465mW.$

Battery capacity = 1500mAh
Lifetime = Battery capacity/ Zigbee current
= 1500/45.23 =33.16 hours

From equation (1), the minimum time the individual takes to walk out of a 5m x 5m room is 3.6 seconds. So it is necessary that the XBee message must be transmitted at least once in every 3.6 seconds in order to detect the absence of person in room.

The message transmission interval of the XBee module can be increased to a particular value if the presence of a person learned from the previously stored database is found to be within the room for longer hours. In this way, the battery usage of the wearable device can be enhanced and stay longer time.

## 6 CONCLUSIONS AND FUTURE WORK

A system architecture that conserves electrical energy by learning the personalized behaviour of occupants in the building was developed. Based on the system architecture, we designed a context-aware wearable device that monitors the proximity of the individual from the switch board and collect the switch on/off activities performed by the individual and a wireless switchboard that continuously collects personalized data from each individual. The system hardware has the capability to learn the individual's behaviour over electrical appliances through the wearable device, wireless switchboard and an aggregator. In this work, the context aware system was tested extensively multiple times for several days and various time durations. The system was also tested for module wise and complete integrated device performance. The results conclude that the proposed system provides the opportunity to collect the data necessary to develop a personalized system for smart buildings with minimum sensors. As future work, a definite algorithm to learn the electrical behaviour of each individual from the data acquired is developed with the system applied to multiple users by incorporating Zigbee range limitation to each rooms.

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