Building Automation System to Optimize Energy Utilization Acquiring the Best Performance of Appliances in a Distributed Network

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***Abstract* — In modern days, optimizing energy consumption is one of the most vital factors to be considered when designing a building. For example, cooling and heating spaces, ventilation, lighting are a few of them. Optimizing energy consumption, while maintaining the human comfort zone, is a challenging task. In this research, we introduced a novel system which is capable of optimizing the energy consumption automatically by considering the environmental factors as well as human behavioural patterns. The new system includes both hardware and software components. The hardware component called Sensor Data Monitoring & Appliances Controller (SDMAC) collects data and the software component Building Automation System (BAS) server processes the data and uses a rule engine to optimize the energy usage while maintaining the human comfort zone within the building.**

Keywords — Building automation system, Energy optimization, Internet of things (IoT), Distributed network

I. Introduction

Building automation systems are a new dimension in construction fields which is used to optimize energy consumption in modern buildings. There are various technologies and methods currently available for this purpose, but still building automation remains a challenging task. In this research, we introduce a novel building automation system which includes hardware and a software component. The hardware component called Sensor Data Monitoring & Appliances Controller (SDMAC) collects data and the software component Building Automation System (BAS) server processes the data and uses a rule engine to optimize the energy usage while maintaining the human comfort zone within the building.

Various methods and algorithms are used in existing BAS[1]. Although past research work has introduced worthy and useful BASs, it is still a challenging task to apply a BAS to an already constructed building because it requires infrastructure modification[2]. Among them, fuzzy logic embedded appliance control algorithms is a widely used technique in existing systems[3]. Fuzzy logic-based systems have shown their robustness in handling environmental factors and appliance controlling. However, the fuzzy logic-based system has drawbacks such as difficulty to update with new hardware devices. Apart from that, designing a BAS for a vast building is a complex task because it requires consideration of a heterogeneous and complex arrangement of the spaces in the building[4]. Besides, the type or the usage of the building also are important factors to be considered when designing a BAS. For example, it can be a warehouse, factory, office or a university lecture theatre. In each case, the duration and the locations of the building used by humans vary. Thus, it is necessary to consider the usage of the building when designing BASs.

The building's purpose, how it is occupied and used is another significant fact since it is directly related to the energy consumption of the building on a day-to-day basis[5]. For example, if the building is utilized as an educational institute, it may be used during regular office hours on weekdays. However, companies, industries, or hotels that are occupied for 24 hours, seven days a week will have high energy consumption all the time. Adopting IoT concepts, several specific circuits and devices have been developed and implemented for BAS solutions[6]. Therefore, currently, hardware platforms have extended their capabilities to communicate through different mediums and protocols [7].

Considering the limitations of the existing BAS and some of the challenges mentioned above, we designed a novel BAS which can manipulate electric appliances using Bluetooth, Infra-red (IR) or any other control medium. The speciality of our system is that it does not connect to the appliances directly but through an interface to the voltage controller (230V), which operates with Pulse Width Modulation (PWM) signals. Thus, the proposed system can manipulate a large number of electric appliances simultaneously, which is a limitation of the existing systems.

II. Objectives

The proposed system manipulates the appliances based on the specifications shown in Table 1 and 2. Those are the environmental factors and conditions considered by the proposed system. Furthermore, the proposed system can work with both digital and analogue signals.

Table 1. Room temperature in general

Temperature(°C)	Condition in General
0-18	Cool
18-28	Normal
28-100	Hot

Table 2. Room humidity in general

Humidity	Condition in General
0-42	Dry
42-62	Normal
62-100	Wet

Another critical factor in a BAS is the selection and execution of rules concerning environmental sensor input

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data. The selection of a corresponding rule may depend on human factors as well as extracted environment conditions.

However, when personalization is required in specific building spaces (cubicle, cellular office area, etc.), the impact of human variability is achieved through analyzing environmental behaviour along with human intervention. Then the proposed BAS requires executing appliance specific rules based on the personalization.

The proposed BAS should be a distributed system since it requires to manage the collection of distributed appliances and system modules as a means of message passing in a Wide Area Network (WAN). The proposed BAS solution should handle the complexity in the orchestration of appliance controlling, and sensor monitoring. The required functionality in distributing sensor and appliance orchestration has been integrated into electronic devices introduced as SDMAC - Sensor Data Monitoring & Appliances Controllers. The main components in the proposed BAS solution (SDMAC devices and BAS servers) should preserve the space and time uncoupling with communication. The discussed aspects of the proposed BAS solution are focused on procuring the best energy utilization and the performance of appliances in a building it is installed.

III. Methodology

The proposed BAS solution consists of two major components as the BAS server and the SDMAC module as shown in Figure 2 and 3. In figure 2, the nodes can be the air conditioning machines, light bulbs or any other electrical appliances. The BAS server manages the communication with a collection of "units" that consists of SDMAC modules and nodes (or appliances that need to be controlled). The "unit" is installed in a cubicle, conference room, server room, or any specific area inside the building where the automation of appliances is required. Since every rule is defined and is controlled according to sensor data inputs and the Key Performance Indicators (KPI) the BAS server is the main module of the system in charge of that task. The installed sensors direct sensor readings to the SDMAC module and the SDMAC forwards the unit sensor input collection to the BAS server. Then the rule engine extracts the Best Matching Rule (BMR) and computes the decision. Afterwards, the BAS server forwards the decision to the correct SDMAC module, and the SDMAC module executes the required controlling commands to the specific appliance according to the decision.

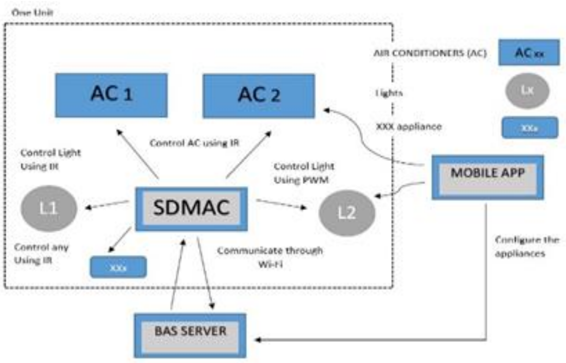

Fig. 1. Unit architecture

The availability of the SDMAC modules is crucial, and an SDMAC module generally mounts on a wall or ceiling. The SDMAC module withstands a load between 3A to 10A. The proposed BAS architecture reflects the potential of extendibility with any type of a sensor with the SDMAC module since it can be introduced as an adapter into the system. In the prototype, the SDMAC module is capable of controlling eight appliances efficiently using the SDMAC has the capability to efficiently manage a load of 5 IR powered appliances and 3 Pulse width Modulation (PWM) (230V) powered appliances.

The implementation of the BAS server has reflected the capacity in controlling several numbers of units connected together. SDMAC module solution enables horizontal scaling. A single SDMAC module can communicate with the BAS server using Message Queuing Telemetry Transport (MQTT) protocol, and the mobile application can also communicate over MQTT in real-time.

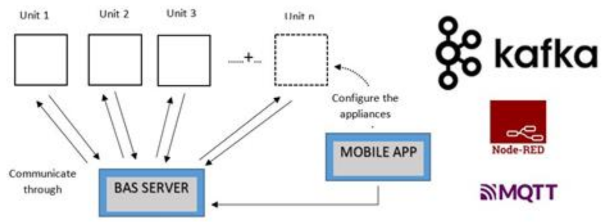

Fig. 2 – Floor architecture

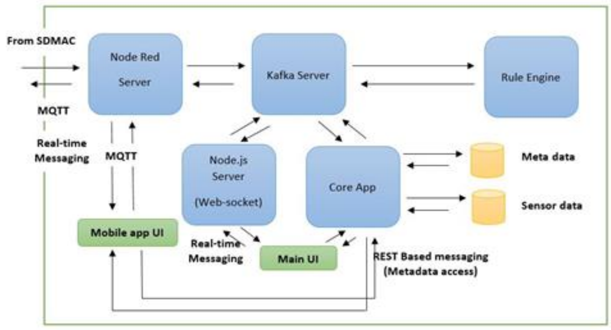

Fig. 3. BAS architecture

The influx database is used to store sensor input data and the "core app" manages the accessibility of data, through data managing interfaces. The rule engine is implemented using Drools, and it is capable of managing rules with forwards and backward chaining. The rule engine communicates with the Kafka server and the NodeJS server exploits as a web socket that connects to the Kafka server while controlling real-time streaming. The use of Kafka as the central message parser has extended the potential in integrating the solution with big data processing [8]. The metadata is the registry of appliances and their specific attributes.

Figure 4 illustrates the prototype of the SDMAC module, and most of the sensors are of passive type. However, it is possible to integrate active type sensors to the SDMAC module as well.

Fig.4. SDMAC device

In a large space, environment monitoring requires the collection of data from multiple inputs from small sensor monitoring devices, leading to higher accuracy in rule extractions. The small sensor monitoring device directly communicates with SDMAC and provides an abstraction on top of the collection of sensors with a sensor validation feature. Validation is required since each sensor has its accuracy level, and due to sudden power changes, some sensors may malfunction.

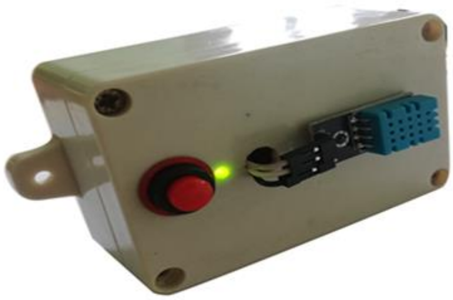

Fig. 5. The small sensor monitoring device

IV. RESULTS AND DISCUSSION

We have successfully tested the proposed BAS system in a real environment. There we performed two types of experiments. First, we tested the fail tolerance of the system. Our system performed consistently without any technical flaws. Second, we tested the energy-saving capability of the proposed system. We measured energy saving capability using a Current Transformer (CT) based real-time energy monitoring system. We used a portable air conditioner placed in a cubicle of 100 sq. ft. for this test. Table 3 shows the specifications of the test environment.

Table 3. General detail of the testing environment

AC Details		Cubicle Area Details	
BTU	12000	Size	100 sq. ft.
Rated Current	8 A	No of person	2

In the test, appliance energy consumption was measured using a portable air conditioner placed in one cubicle of a single floor. The air conditioner had dynamic state-changing capability against time by consuming considerable energy of the building. Therefore, this was an ideal appliance to examine energy usage in the existing building. According to the environmental condition of the room temperature and humidity was considered as sensor data.

Based on the experiment, the energy consumption of the air conditioner was measured within a time span of 180 minutes. The energy consumption had minimized by nearly 1.118 kW/h. The air conditioner's power usage without using the BAS was 3.331 kW/h while using the BAS with rule-based controlling was 2.213 kW/h. The experiment emphasized that the rule-based controlling worked perfectly and the appliances' functionality was controlled according to the environmental factors on which the appliance is dependent on resulting in reduced power usage. Assuming every cubicle area of the building has similar characteristics then each cubicle of the floor could be measured using the above the mentioned method.

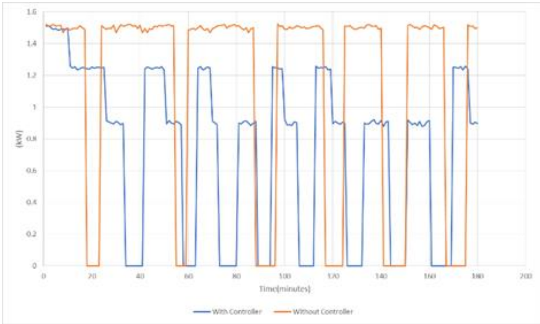

Fig. 6. Energy consumption level comparison (180 min behaviour)

V. CONCLUSION

In this work, we have introduced a novel building automation system which includes both hardware and software components. The uniqueness of our system is that it can control or manipulate large electric appliances simultaneously while preserving the human comfort level in the building. The experimental results show that our system saves a significant amount of energy and can run flawlessly for extended periods without interruptions.

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