A Low-Cost IoT Based Buildings Management System (BMS) Using Arduino Mega 2560 And Raspberry Pi 4 For Smart Monitoring and Automation

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Abstract *–This work presents an internet of things (IoT) based building management system (BMS) for monitoring, control, and energy management in buildings to provide an efficient way of energy utilization. Existing systems mainly provide monitoring of different parameters with limited controlling/automation functions. Existing solutions also do not provide automatic decision-making, advanced safety management, and resource tracking. However, the proposed system provides a comprehensive way of monitoring, controlling, and automatic decision making regarding different environmental and electrical parameters in buildings, i.e., temperature, humidity, dust, volt, etc., by using a low-cost wireless sensor network (WSN). The architecture of the proposed system consists of five layers and uses analog sensors which are connected to Arduino Mega 2560 microcontrollers for data collecting, NodeMCUs ESP8266 for wireless communication, Raspberry Pi4 microcomputers for decision making, and nod-RED dashboard which runs locally on a Raspberry Pi 4to provide a friendly end-user interface. The system also uses the Message Queuing Telemetry Transport (MQTT) communication protocol through Wi-Fi and completely relies on the local devices in the architecture and does not need cloud computing services. The proposed system provides two different kinds of automation, i.e., safety automation for the safety of different devices with advanced features, and energy automation. The proposed system is also able to provide humidity control inside a room and to track and count the available resources in any facility. The proposed system is low cost, scalable, and can be used in any building. Simulation results show that the proposed system is highly efficient.*

Keywords: *Automation, Building Management Systems, Energy Management, Internet of Things, Monitoring*

1. INTRODUCTION

Energy saving is one of the most critical challenges of this century. The increase in energy consumption, especially in residential buildings, has made this issue more critical. This is because residential/commercial buildings have now become an essential part of our community to live peacefully. However, many other factors, i.e., maintenance, power line health, etc., are also needed to be taken care of along with energy consumption for a smooth life in these buildings. Globally, the residential sector consumes around 41.4% of total energy consumption, which is considered a high percentage of energy usage. Therefore, many countries are trying to reduce this percentage by making an accurate analysis of different kinds of loads [1,2].

There is also a growing concern for the mismatch between the energy efficiency expected for residential buildings and the real output assessment, usually referred to as the performance gap, i.e., actual usage and expected usage. Typically, the reasons for the performance gap are distributed among multiple factors such as incorrect assumptions and insufficient forecast of the energy models at the design stage, the difference between the design and construction stage, not operating the system according to the instructions, and installation & maintenance challenges/issues, etc. [3]. Minimizing the performance gap is also a critical challenge for public-private social housing, where energy efficiency initiatives are the primary driver. It has also been proved that the high energy efficiency of residential/commercial buildings is considered as a leverage for the governments that need to be taken care of [4].

Similarly, with the increase of the population and the evolution of the world, many smart concepts have also been developed by the scientific community, i.e., smart houses, smart vehicles, smart health, etc. These smart concepts enable people to live comfortably by providing a wide range of accessibility. Furthermore, the scientific community is also developing a new concept of smart buildings. In smart buildings, an intelligent computer-based system, i.e., building management system (BMS), consisting of hardware & software will be installed to monitor and control different appliances (Heating, ventilation and air-conditioning, power systems, etc.) and services (security access control, elevator, and safety system, etc.) to increase the energy efficiency of the buildings. BMS coordinates all the appliances and services within a building to work/operate as a single complete integrated system.The main purpose of this concept is to reduce the energy consumption of the residential/commercial buildings up to a reasonable level by limiting the operation of the appliances according to a specific need, i.e., temperature, etc. This concept is a framework that incorporates remote control technologies to allow the end-users to monitor and manage energy consumption operations for the appliances [5]. Overall, BMS provides efficient usage of energy, healthy impact on the environment, peace of mind, improved security &better appliance life. Although BMSs existed since the 80s, approximately only 15% of buildings use this technology due to its overpriced costs and limited functionality [6]. Up to 30%, saving can be achieved in energy bills by using BMS, but only 9% of the world's energy is controlled by the BMS [7]. A more unified approach is required by manufacturers to build BMSs to provide more functions and enhance compatibility.

Moreover, the use of information and communication technology, i.e., IoT, is used to improve the efficiency of energy consumption in the building sector. IoT refers to the millions of physical devices that are connected to the internet to operate/control them wirelessly. The IoT technology provides a wide coverage area, low energy consumption, low cost, and outstanding connectivity. IoT concept capitalizes a vast majority of analog sensors as the main component for its operation [8]. Merging the residential buildings with the IoT concept offers an opportunity for the better use of the building's energy. To optimize the energy usage in buildings, many solutions have been developed previously such as applying a monitoring system that uses sensor devices to analyze the data, i.e., humidity, heat, vibration, current, voltage and pressure, etc., taken from these buildings. Monitoring and controlling these parameters makes it much easier to deal with the energy performance [9,10].

The existing literature generally discusses building automation systems (BAS) and building management systems (BMS) for the management of different building parameters. Most of the solutions in the existing BMS do not provide the automation feature, except a few of the papers discuss the automation with limited goals or as future work. The existing solutions leave the decision-making to the end-user as discussed in [11, 12]. Similarly, building automation systems (BAS) as discussed in [13] provide only limited energy and safety automation, i.e., turning on/off the lights if the system senses a human walk-in corridor, automatic water spray if smoke sensors detect fire, etc. BAS also does not provide facility management and enhancement of interior comfort. Moreover, the majority of the commercially available BMS systems are designed to implement very specific functions chosen by the manufacturer. If more functions are required, then the provider will charge extra or the order will be refused. These systems also suffer from inefficient automation, increased maintenance & security costs, etc. [14]. However, this work presents a comprehensive BMS system that covers all the deficiencies in the existing BAS and BMS by introducing an extremely compatible/scalable system due to fast data collection and automatic controlling.

The proposed system is not only capable of comprehensive monitoring and controlling, but also provides a new feature of taking decisions automatically, i.e., automation according to the desired goal and threshold set by the user. The proposed system also provides resource tracking and system safety with advanced features. The proposed system utilizes IoT technology for the monitoring, controlling, and smart automation of the building ambient parameter measurements, i.e., current, voltage, vibration, dust level, humidity, temperature, water pressure, etc., to provide efficient energy utilization in these residential buildings. Automation has an impactful role in energy management because machines, i.e., computers, etc., are more consistent in performing as compared to humans and also reduce exposure to control problems [15].

The work presents two kinds of automation features, i.e., safety automation and energy management automation. The parameters are periodically measured in the safety automation based on some predetermined value and the system can take up to four unique decisions for the safety of any device. The proposed system checks/monitors the devise's reading variation from 0 to 30%, and takes appropriate actions accordingly at a different level of variation, i.e., less than 10%, 20%, and 30%, etc., to provide safety of these devices. For energy management automation, the user can set a daily wattage limit for each room/unit by using the dashboard. If the wattage readings exceed the specified limit, the system tunes down the wattage of the room to the desired level. Simulation results show that 90 Wh energy can be saved if a 60 W bulb is used for 10 hours a day. Similarly, simulation results show that the proposed system saves up to around 2600 Wh energy for a room in one day. These energy savings can be further enhanced/adjusted depending on the end-user's comfort level. Similarly, for resource tracking, a sensing circuit is placed in the storage room that can track and count the items to detect how many objects are available at any time. The proposed system is capable of tracking up to 540 units in any building, and it is easily extendable. The proposed system also keeps humidity inside a room within limits, i.e., between 35-55%, by activating and deactivating the humidifier through an automatic control mechanism.

The architecture of the proposed system consists of five different layers which are the perception layer, transport layer, middleware layer, application layer, and business layer. We chose to build our system based on five layers to elaborate the system more comprehensively and efficiently. The paper also discusses in detail how the data is collected from analog sensors, then processed and uploaded to the MQTT broker. The processing unit in the system, i.e., the middleware layer, is programmed to take actions according to the predefined thresholds regarding safety and energy by enhancing the IoT data analytic level in the system. Mainly, the proposed BMS goal is to reduce the energy consumption of buildings and provide an automation system that can predict any emergency before its occurrence. We used a Wi-Fi network for high-speed communication which is very essential for safety automation as compared to the existing solutions which use Zigbee or Lora communication which has a low speed. Based on the described features, the proposed system provides enhanced safety, more energy saving by using automation, and efficient resource tracking as shown by simulations.

This article furthermore includes multiple sections which are arranged as follows. Section 2 presents the related work. Section 3 presents the architecture of the system and discusses different layers. Section 4 discusses the data collection and decision-making procedure, including the idea of how the different devices communicate with each other. Section 5 shows the simulation of the proposed system and section 6 is the conclusion.

2. LITERATURE REVIEW

The existing literature discusses very little work related to the IoT in BMS. One of the papers [16] introduced an industrial IoT system that allows operators to control industrial applications using the Raspberry Pi 3 B. The paper claims that the IoT in buildings significantly reduces operating expenditures. The proposed approach only focuses on industry-related applications and monitors just three parameters which reduces the feasibility of the system. In [17], an efficient and low-cost IoT-based building monitoring system is implemented by using a Raspberry Pi microcomputer which collects the environmental parameter such as temperature and humidity. An advantage of this system is that it eliminates the need for high-power computers to analyze the collected data. The system uses the Zigbee protocol for communication which considers a battery-friendly protocol, but this protocol has short-range coverage as compared to Wi-Fi or Lora.

Paper [18] demonstrated the rapid growth of IoT technology in BMS and reviews the related works of IoT and big data analytics in smart buildings. The paper implies that integrating IoT in building management will lead to the improvement of residents' comfort by simplifying the building management. However, the huge amount of collected data is a drawback in this BMS system. Paper [19] utilized a web-based tool that stores, collects, and represents the energy data of buildings from heterogeneous and dynamic sources to enhance the interactivity of building energy management systems. The purpose of such a system is to contribute to energy saving and behavioral change, i.e., finding monitoring points and monitoring objects for intelligent power supply, etc. However, the presented solution provides only monitoring options, which limits the system potentials such as controlling.

A real-time IoT platform for building health monitoring was proposed in [20]. The system encompasses Piezoelectric sensors (PZT), an Arduino, and a NodeMCU ESP8622 Wi-Fi chip. The PZT is used to generate and receive Lamb waves to determine and analyze the health of the concrete structure. The presented IoT could detect the cracks present in the building and other potential problem areas. In [21], an intelligent power monitoring of building equipment based on IoT technology is presented. The solution focuses on implementing a monitoring system for indoor electrical equipment. Paper [22] introduced a system for data acquisition and control for homes by using the principle of IoT. The system implements a Zigbee approach and a single chip controller to handle the data connection process and implement various types of sensors to obtain the readings. However, the proposed system does not provide a clear circuitry or simulations.

Similarly, paper [23] proposed a design of smart panels that could be used for building management purposes. These smart panels control loads using the principle of IoT claiming that it increases the protection of the operator by allowing them to observe and control the loads from a distance. The system uses NodeMCU to monitor the main electrical parameters such as current and voltage. However, the system is only aimed to control loads with limited functionality, i.e., connect and disconnect. Paper [24] illustrated a monitoring solution for zero energy building management by using power line communication (PLC) and android application. This building management system enables the monitoring and control of the power usage, through an android application to enhance the sustainability of the building. However, the PLC technology can only be installed in existing power lines. A smart building automation system (BAS)was also proposed in [25]. BAS controls the lighting including artificial lighting i.e., on/off & dimming control, etc. The system also controls air conditioners with some safety features i.e., fire alarm and gas alarm, etc. A limitation of the system is that it presents fewer sensory and automation options for a building automation system.

Paper [26] presented a monitoring and diagnostic system to improve the building operations. This system provides a prototype information monitoring and diagnostic system (IMDS). The IMDS consists of multiple high-quality sensors, data collecting software & hardware, and a web-based remote system for information accessibility. The web-based remote enables the user to identify and control problems. However, the system only shows an improvement in the building's climate. Paper [27] discussed a remote monitoring system for building automation, i.e., BAS by using VxWorks. The BAS consists of a PC104 bus, which adopts VxWorks operating system and AMD processor. The system helps to improve the automation of several operations. Paper [28] proposed a monitoring and controlling system for house lights and appliances using the principle of IoT. The proposed system used mega Arduino and sensors for data collection alongside MIT app inventor to design the interface of the system. The Bluetooth was used in the proposed system for communication which limited the range and ultimately provided inaccurate current and voltage readings.

Paper [29] discussed an IoT system based on cloud computing that would help in efficient building energy management for countries that encounter electrical power shortages such as Nigeria. The proposed IoT system supports utilizing the little available energy by automation and it collects data for future planning. The paper indicated that one shortcoming of the system is the method of sensing which is not cost-effective for their native environment. Paper [30] introduces a BAS system by using two approaches, i.e., programmable logic controller and image processing. The proposed system uses motion and light sensors to indicate the presence of individuals. For AC controlling, the system uses image processing to indicate the number of individuals in an area to control the temperature and operation state (on/off). However, the proposed system is not able to monitor the operational states of the loads, i.e., no monitoring of the health of the electric machines.

The comprehensive literature review indicates that the current presented building management systems (BMS) are mainly aiming to monitor specific ambient parameters such as temperature, humidity, and/or provide limited controlling and automation, i.e., leaves the decision making to the user. Also, the current building automation systems (BAS) have limited goals of controlling and automating. Only the on/off capability of switches, adjustment of the air conditioner according to the number of people in the room kind of functions can be performed which ultimately limits the overall system efficiency. These systems do not provide a complete understanding of the operating loads' states and conditions, i.e., machine health, etc., and do not provide facility management options at all. However, the proposed system in this work does not only provide all the features of BMS and BAS systems with better monitoring and controlling of different parameters but also provides the decision automatically, i.e., automation, to achieve the desired goal and threshold set by the user. The proposed system also provides automatic safety with advanced features for different equipment/machines along with resource tracking.

3. ARCHITECTURE

IoT architecture consists of many elements such as sensors, actuators, protocols, cloud services, layers. gateways, etc., which are connected to collect, store, and process data to perform desired functions sent via a user application. The distinguished layers in the IoT architecture use different protocols and gateways to keep track of the system's consistency.

At the beginning of the new era of IoT technology implementations, the proposed IoT architectures generally consisted of three layers, i.e., perception, network, and application layer [31]. However, these architectures are not able to provide a complete visualization of the IoT main components such as data processing and security [32]. Therefore, researchers have modified and added two more layers known as transport and middleware layers to acquire a comprehensive conceptualization of the IoT system [33]. Table 1 shows the different IoT layered architectures [34,35]. In this paper, 5-layer architecture is used and presented from the bottom (perception layer) to the top (business layer) to cover all the necessary details in the implementation process. Fig. 1. shows the complete architecture of the proposed solution.

Table 1. IoT architecture.

3-Layer architecture	4-Layer architecture	5-Layer architecture
Application layer	Application layer	Business layer
Network layer	Processing layer	Application layer
Perception layer	Network layer	Middleware layer
--	Perception layer	Transport layer
--	--	Perception layer

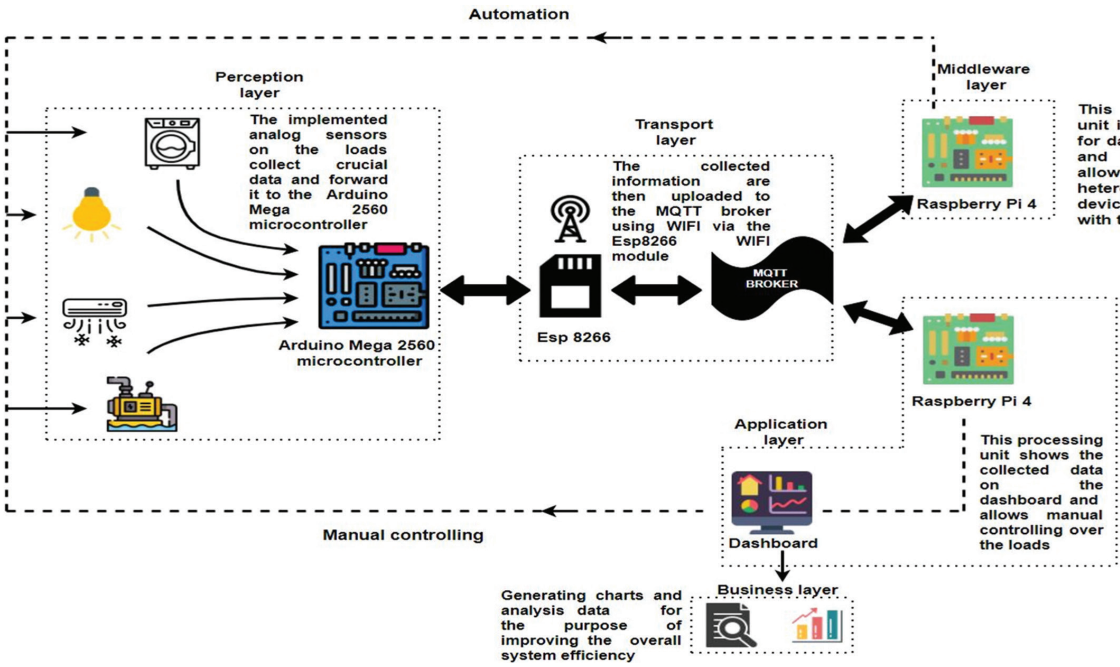

Fig. 1. The complete architecture of the proposed solution.

3.1 PERCEPTION LAYER

The perception layer, i.e., the recognition layer, is the lowest layer of the conventional IoT architecture. The main objective of this layer is to collect useful data from the environment, i.e., physical parameters, other smart objects, etc. The perception layer collects information using interlinked data collection technologies such as heterogeneous devices, environmental sensors, and WSNs. The collected data is converted to digital data and transferred to different layers, i.e., application and middleware, etc., in the network for further processing [36].

This form of data collection raised a lot of security-related concerns, i.e., eavesdropping, node capture, fake node & malicious, Replay & timing attack, etc., which leads to the development of various security approaches to protect the perception layer from unauthorized access. The process of gaining authentication and authorization is known as access control which is achieved by two main methods Role-Based Access Control (RABC) and Attribute-Based Access Control (ABAC). In the RBAC approach, the roles of the users are already defined, limiting the number of resources authorized to the user and allowing him to access specific information related to his role. On the other hand, ABAC grants the user's resources or data access based on attributes, i.e., user attributes, environmental attributes, resource attributes, etc. ABAC approach provides a much-reduced risk by making the access more flexible and scalable supporting both fine-grained access and dynamic extension for a large scale number of users [37].The proposed system also uses the ABAC approach due to its sufficient scalability and flexibility in providing fine-grained access control alongside the ability to operate in a complex system with a large number of users making it more suitable and adaptable to the access control of IoT. To obtain an accurate analysis of the load behavior in our design various types of sensors were implemented to collect important information during the load operation time as shown in Table 2.

Table 2. Implemented sensors

Sensors	Monitoring
TMP36 Temperature Sensor	Ambient Measurement
GP2Y1010AU0F Dust Sensor	Ambient Measurement
AHT10 High Precision Digital Temperature and Humidity Sensor Measurement Module I2C Communication	HVAC Unit Room Humidity Monitoring
SW-420 Vibration Sensor	HVAC units-Water Pump Motors
SEN0257 Gravity Water Pressure Sensor	Water Pump Motors
BMP180 Water Pressure Sensor	Water Pump Motors
ZMPT101B Single Phase AC Voltage Sensor	Electrical products-HVAC units
Allegro ACS712 AC/DC Current Sensor	Electrical products-HVAC units

For environment analysis, temperature, humidity, vibration, and pressure sensors are implemented along with voltage and current sensors for electrical analysis. Each of these sensors is distributed on loads based on the parameter that defines its behavior. For example, a water pump motor behavior is defined by water pressure, motor temperature, and vibration setting. A reference point is set for all these parameters and the operation of the motor is analyzed based on these parameters which provide us a clear view of the motor operation condition. These readings would also make it easier for the operator to define any occurring liabilities. The readings from the sensor are collected, organized, and converted to digital data by using an Arduino Mega microcontroller 2560 which is physically connected to analog sensors. The Arduino mega microcontroller can handle up to 16 analog signals simultaneously providing great sensing expandability to cover a complete residential unit or a room. Fig. 2. shows the connectivity between the sensors and Arduino mega 2560.

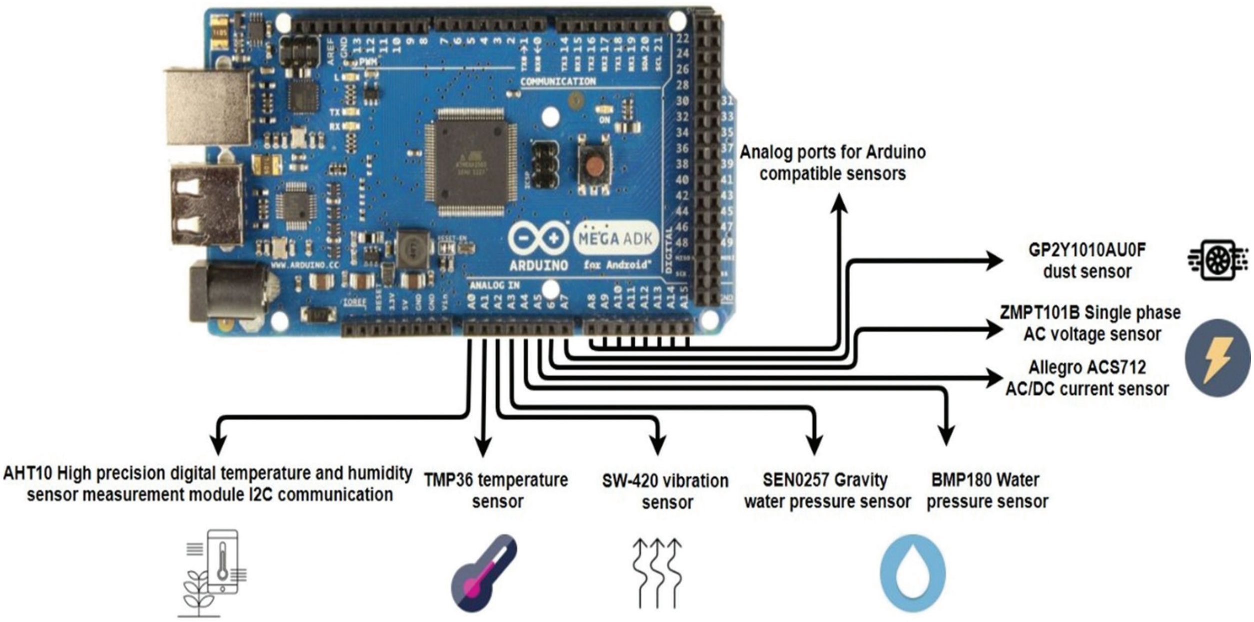

Fig. 2. Connectivity between analog sensors and Arduino Mega Microcontroller

3.2 TRANSPORT LAYER

The transport layer plays a major role in the WSNs that is established by the IoT system [38]. After collecting the ambient parameter measurements by the sensors in the perception layer, the transport layer is responsible for transmitting the collected data from the Arduino mega platform to the processing unit i.e., the middleware, etc., and vice versa. Several networks have been used in this layer such as Bluetooth, Zigbee, Lora, Wi-Fi, and cellular. Lora network has been used due to its capability to transmit data over long distances which could reach several kilometers with low energy consumption as proposed in [39,40]. However, since it uses low energy, the bandwidth of Lora channels is small compared with other networks such as Wi-Fi and Zigbee and the data rate is very low i.e., 0.3-50 kbps [41].

The low data rate can only be accepted if the IoT system is used for monitoring. However, the proposed BMS system in this work also provides controlling in addition to monitoring to provide simultaneous bidirectional communication for better management which cannot be provided by the Lora network. Therefore, the proposed transport layer (Ergo) uses Wi-Fi as a communication network. The advantage of the Wi-Fi network is that all smart buildings nowadays have Wi-Fi coverage and there is no need for additional gateways (routers) in suchbuildings while using Wi-Fi as needed by Lora or Zigbee networks. Additionally, the current Wi-Fi standards provide a bandwidth of 2.4-5 GHz, which is sufficient for faster communications without any delay, and further enhances user experience [42]. Fig. 3. demonstrates the range of networks correlated with their bandwidth [43-45].

To grant Wi-Fi connectivity to the Arduino Mega 2560, NodeMCU ESP8622 is attached to the Arduino microcontroller. The ESP8622 is a low-cost firmware kit that is used in Arduino IoT projects and communicates with sensors via serial communication and is responsible for transferring the data from the Arduino Mega to the gateways i.e., routers. The gateway is the main bridge that links between the middleware and sensors, microcontrollers, actuators, and relay modules. The communication protocol, which is followed by the Wi-Fi network is the MQTT network protocol, which is an IoT machine-to-machine connectivity protocol and is used for bidirectional publish-subscribe data transport as illustrated in Fig. 4. MQTT is also capable of providing connections at remote locations having constrained resources and at low bandwidth environments.

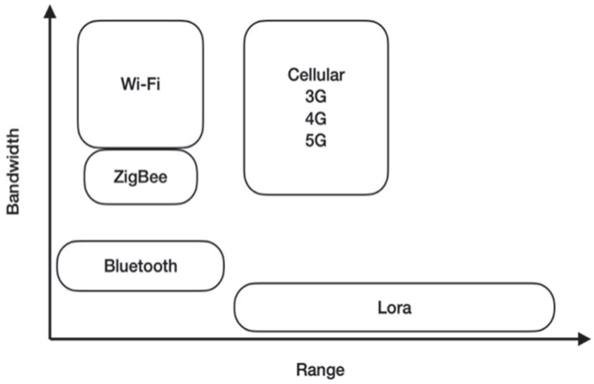

Fig. 3. Wireless networks' bandwidth correlated to their range.

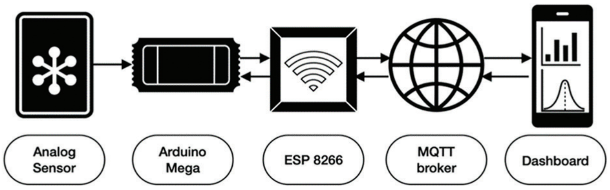

Fig. 4. MQTT communication between sensors and dashboard.

3.3 MIDDLEWARE LAYER

Heterogeneous device interaction within the IoT network is a complicated process since each device provides a unique data type, operational behavior, and supports different communication protocols to perform a different operation for the required interaction. These issues also arise when these heterogeneous devices interact with the data collection devices which collect information from the surrounding environment. All of these issues are addressed in the middleware layer of the IoT, which is also known as the processing layer. This layer stores, analyzes, and processes a large amount of data coming from the transport layer, and also manages and provides several services to lower layers. The middleware layer also fulfills the IoT domain for various applications such as managing a large amount of information, conditional awareness, adoption, scalability, cloud computing, databases, bid data processing modules privacy, security, automation, device locating and management, etc. Therefore, the middleware layer is a software platform represented by some sort of computing process where all the heterogeneous sensor domains of the applications are joined to create a processing unit that is responsible for the devices' information interactions and management in a unified way. [46].

In the proposed system, we selected a low-cost Raspberry Pi 4microcomputer to behave as the middleware layer due to its ability to perform different functions, i.e., structure complex data models, supports various operating systems, supports multiple coding languages, and can handle huge processing power in a compact board, etc. The Raspberry Pi 4 analyzes, processes and manages the information which is uploaded to the MQTT broker. The gathered and processed data is also saved in a comma-separated values (CSV) file, i.e., a file that saves data in the form of spreadsheets and tables. It is always easy to import and export data using programs that similarly save data. Therefore, storing data as a CSV file assist in communication between the devices in the network as a unified data language. This middleware approach allowed our system to collaborate in communication and provide information exchange along with massive scaling flexibilities of devices, which is due to the huge computational power capability of the Raspberry Pi 4 to operate a large number of devices at the same time [47].

In the proposed system, two controllers are used (Arduino Mega and Raspberry Pi), as each one of them has unique functionality and tasks to perform. The Arduino is responsible for collecting the environmental signals through sensors and converts these signals into digital form for further processing. However, the Arduino hardware is limited and cannot be used for automation or dashboard operations. Therefore, Raspberry Pi is used, which works like a computer or processing unit for the overall system. Raspberry Pi processes the collected data, makes it visualize on the dashboard, and performs automatic decisions. Therefore, Arduino's task is to do datafication, and Raspberry's task is to do automation.

A primary concern in the proposed system is handling a large amount of data coming from the sensors attached to the loads as Arduino mega is collecting data continuously and a huge amount of data will be accumulated as time will pass. To overcome this challenge, the system is programmed to extract only useful information by managing the raw data into more managed groups (CSV) files and removing needless loads of data as discussed in paper [48]. Similarly, in cloud-based application network delay is generally higher due to the sharing of the same communication link in the cloud by multiple loads. This issue is resolved by implementing a specific mega Arduino microcontroller for each building unit which will increase the bandwidth available for each load and will reduce the round-trip time and network congestion.

3.4 APPLICATION LAYER

The application layer provides monitoring and controlling. This layer is the end-user dashboard layer, i.e., interface, which enables the users to interact and communicate with the IoT devices in the network, as it is capable of providing application-specific services to end-user such as smart homes, smart health, and smart cities, etc. It displays sensor readings, which are uploaded to the MQTT broker in an organized and simple way, i.e., easily understandable to the end-user. Furthermore, this layer empowers the user to remotely control the devices in the system, i.e., moving the actuator parts for motion purposes, switching the electrical relay modules for energy management purposes, etc. The design of the application layer heavily relies on the understanding of the end-users and their main goal of using the application.

In this work, the application layer displays the environmental measurements of the building such as temperature, humidity, power, etc. The dashboard is programmed to notify the end-user in case of any abnormal measurements and the IoT system immediately acts to protect the electrical devices accordingly. Moreover, in the dashboard, the user can control the electrical devices which are connected to the system such as air conditioning units to achieve facility and energy management. Additionally, the dashboard also shows the total number of units/resources in the warehouse for tracking and counting purposes, i.e., resource location tracking/counting, etc. We built the application layer using the Node-RED platform. This platform is an open-source flow-based programming tool for connecting hardware devices and is capable of providing a set of nodes to quickly create a live data dashboard. The dashboard will run locally on a Raspberry Pi 4 microcomputer as a web server which can be accessed via the Wi-Fi network of the building through computers or mobile phones. Fig. 5. shows the proposed IoT dashboard which displays the available monitoring and control options in the system.

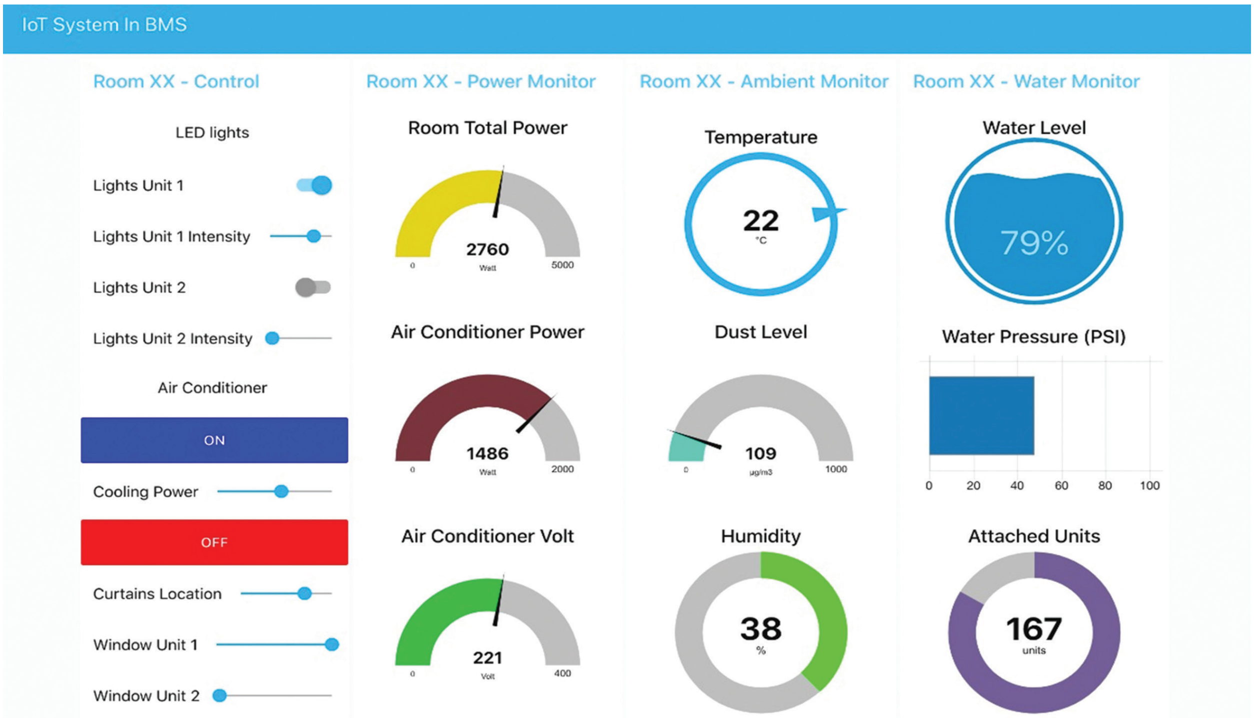

Fig. 5. Proposed IoT Nod-RED dashboard built on Raspberry Pi 4.

3.5 BUSINESS LAYER

The top-level layer in the IoT architecture is the business layer which acts as a manager of the whole system. This layer manages and controls applications, business, and profit models of IoT, along with the user's privacy. Hence, the business layer coordinates business logic, top-level requirements, and various other management operations to achieve a successful and durable architecture that provides continuing values to the system and operator. The business layer takes the responsibility for the management of the overall IoT system by creating graphs, flowcharts, business models, and much more based on the information gathered from the analyzed applications as this layer can create, store, and change the acquired information. This whole process ultimately increases the system efficiency by introducing future actions and strategies that would contribute to achieving success for the implemented IoT system.

4. DATA COLLECTION AND DECISION MAKING

4.1 ANALOG MEASUREMENTS

The flow chart for data collection is shown in Fig. 6.The data collection process starts with the perception layer in which the analog sensors collect the ambient measurements and send them to the Arduino mega 2560, which converts the analog signals into digital signals. The number of required microcontrollers for each unit, i.e., area or room, depends on the application. It is sufficient to provide each room with one Arduino mega to collect temperature, humidity, dust, water pressure, water level, voltage, current, and power of the room in residential applications since each Arduino mega microcontroller is capable of processing up to 16 analog signals.

A NodeMCU ESP8266 which is physically connected to the Arduino mega receives the digital signals via serial communication. Both Arduino mega and ESP8266 are programmed in C++ language. After receiving the data, the ESP8266 uploads the readings of each room to its specified topic in the MQTT broker and each sensor reading to its assigned subtopic in the form of topic/subtopic as demonstrated in Fig. 7., which shows the readings of temperature, dust and humidity of a room xx with date and time. Since MQTT is a publish-subscribe communication protocol that is implemented in the transport layer of the proposed IoT network, the ESP8266 is publishing the readings to the predefined broker and any device which is subscribed to the broker can receive the published information. Subscribing to the MQTT broker can be achieved via different devices and platforms such as personal computers, mobile phones, the Nod-RED dashboard, and the middleware of the system. Both middleware and application layers are subscribed to the topics and receive data directly from the broker. The display elements on the dashboard of the system are subscribed to the subtopics of the broker to display the readings directly in the user application and the middleware computer (programmed in Python), the data is imported from the broker for further analysis and decision making such as automation as shown in Fig. 6.

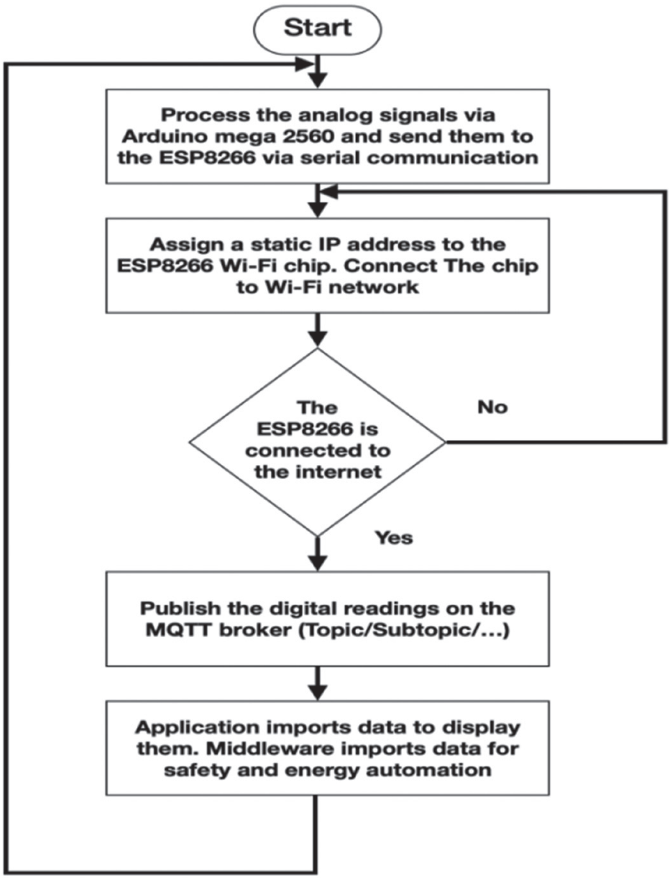

Fig. 6. Data collecting flowchart

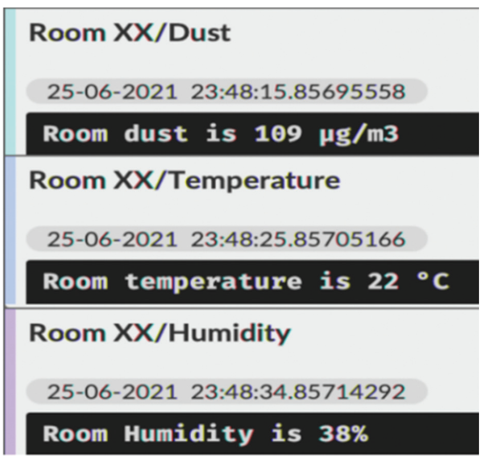

Fig. 7. Sensor reading uploaded to the broker

4.2 SAFETY AUTOMATION

The new key aspect of the system is also its capability to perform actions without human interaction, i.e., automation. The goal of automation is to enhance the efficiency of energy utilization and keep the loads in healthy conditions in case of any malfunction. The proposed system is capable of providing two kinds of automation, i.e., safety-automation, and energy-conserving automation. In safety automation, two kinds of operations can be done as shown in Fig. 8b.Either the load can be shut down in case of major malfunctions or the operation intensity can be reduced temporarily, if the problem can be fixed by the operator in a short time. The system sends a notification of the problem in both cases informing the operator.

To obtain the safety automation, the decision-making process is implemented in the middleware layer of the IoT system using the Raspberry Pi 4 microcomputer by adjusting a predetermined range of the parameters utilized by the loads that would determine the load condition. The decision-making process also varies between loads depending on the number of parameters used in making that decision and the impact of the malfunction itself. For example, a slight increase in the air conditioner unit temperature wouldn't be sufficient to start the decision-making process, but on the other hand, a slight change in the humidity and vibration of the air conditioner units would stimulate the IoT network to perform the required action. However, dramatic change in any parameters is enough to activate the automation process and the corresponding action will depend that how much change has occurred in the parameter reading. In our proposed system, a measured parameter is compared with the predefined limits, and if there is a 10% increase or decrease in the reading, i.e., variation, no action is taken, and only a notification is sent to the operator/management. If there is a 20% increase or decrease in the reading, i.e., variation, operation intensity is reduced and this reduction continues until the reading tolerance is below 20%. The operator/management is also informed during this process. If the reading increases or decreases more than 30%, i.e., variation, immediate action is taken to shut down the load for maintenance purposes due to some major malfunction. The decision-making process combines multiple parameter readings to implement the suitable action based on a predetermined function applied in the Raspberry Pi 4 which is implemented in each unit (e.g., room) to remotely control the electrical switches i.e., relay module connected to the loads, etc.

4.3 ENERGY AUTOMATION

Energy conserving automation is shown in Fig. 8a. The system integrates energy-saving methods via automation by measuring power consumption, i.e., a way to improve energy management in buildings. In every room, a Raspberry Pi 4 device will be programmed by using the python language in the middleware layer to collect and analyze the power behavior of the room. The analysis of the power is conducted to generate a mathematical estimation, i.e., estimating average power consumption, to take actions automatically. Estimating the average energy consumption in each unit helps to attain a goal limit via the dashboard that the middleware layer must achieve to minimize energy consumption. The business layer then presents the energy consumption of a certain unit, i.e., room, in the dashboard using statistical charts/figures. In our work, the proposed system calculates the current power consumption in a room, as shown in Fig. 8a. Then the proposed system estimates the power consumption of the room for the next one hour by generating a mathematical model.

The estimation is established periodically with a period defined according to the building nature. In our work, we consider that a period of one hour is sufficient for the residential buildings. Thus, for each hour the system calculates the average power of the room for 2 minutes and estimates the power for the next 58 minutes. Each room has its own Raspberry Pi 4 processing unit as a middleware layer which generates a mathematical estimation using linear regression and acts accordingly. Then the system measures the consumed energy of the room, and If energy consumption is more than the limits, the system automatically starts to tune down the lightning and cooling power of the air conditioner of that room to curtail the energy consumption. For example, if the average daily consumption of a room is 23,000 Wh, the management can set a goal of 20,000 Wh as a way to reduce electricity consumption. If energy consumption increases beyond this limit, the system automatically starts to tune down to curtail 3,000 Wh daily.

This approach is implemented without compromising the interior comfort or the intended goal of the loads. The maximum level of tuning down can be defined by the users to maintain the convenience of the system through the dashboard where the user specifies the minimum threshold level for cooling power or lightning, i.e., the automation system cannot go below. However, if energy consumption is close to the limits, the analytic tools also notify the user/management to take necessary actions, i.e., turning off any appliance, etc., to conserve the energy.

4.4 RESOURCE TRACKING

The proposed system also provides a resource tracking feature as shown in Fig. 9. With analog inputs, the digital ports of the Arduino Mega are utilized in collecting data for resource tracking. The digital pins are connected to a high input voltage, i.e., 3.3 volts, and a mechanical switch is placed in between the input voltage and the digital pin. The mechanical switch is located beneath the resources such as paint cans. If the resource is placed at its designated location, then the mechanical switch will connect to the circuit and 3.3 volts will be applied to the pin which is associated with the resource, and it will indicate that the item is attached or vice versa. This approach will help in counting the number of available resources in certain locations such as warehouses, buildings, etc. Implementing resource tracking via this method in buildings will help in minimizing errors and provide constant feedback about the status of the resources regarding their location and quantities. This approach is scalable because each Arduino mega has 54 digital inputs, and 10 Arduino mega are sufficient to track up to 540 units. Future work can be enhanced by using computer vision in which counting is achieved via visual computing through cameras and this approach can cover larger areas with massive scalability. Another advantage of the system is its flexibility, and it can be used for counting different resources, i.e., paint cans, soft drinks, water bottles, devices, etc.

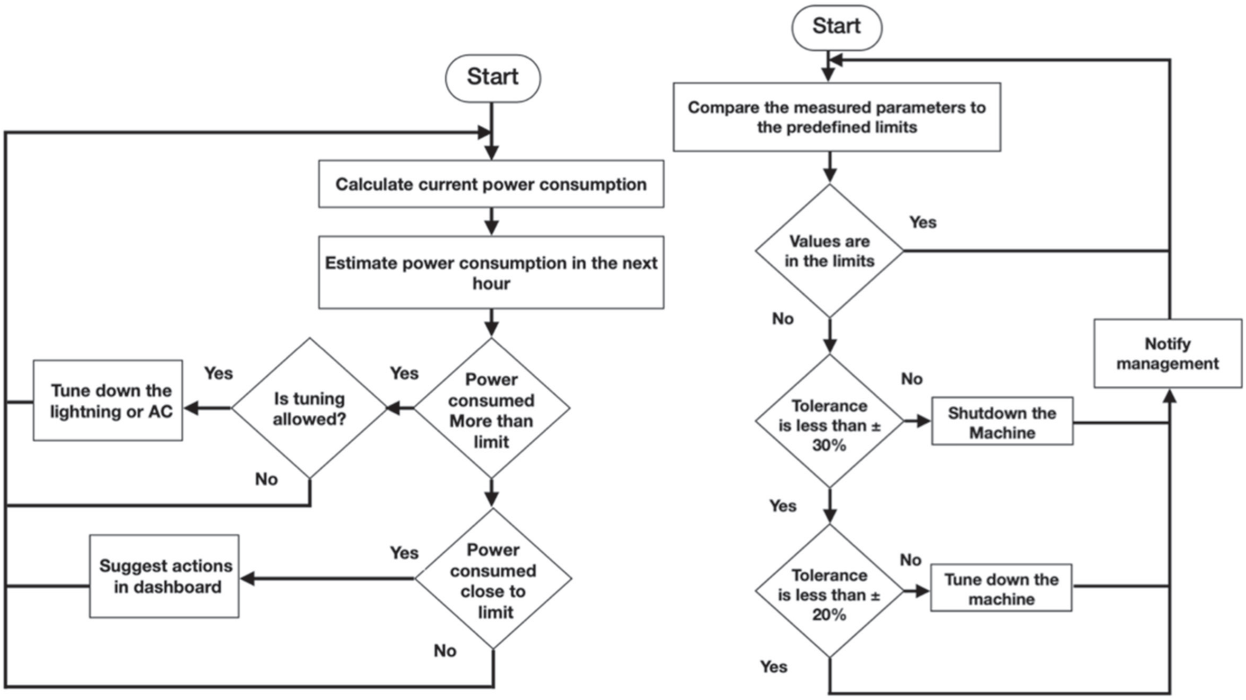

Fig. 8. Automation flowcharts. (a) Energy conversion automation flowchart (b) Safety automation flowchart

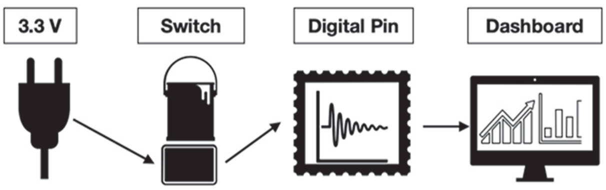

Fig. 9. Resources tracking mechanism

5. SIMULATION

Proteus 8 professional software is used to create the circuitry for simulation. This software provides a wide range of electronic devices, i.e., Arduino mega 2560, NodeMCUs, environmental sensors, etc. The user can also download multiple electronic device libraries to encompass all kinds of electronic tools. The proposed BMS monitoring system is composed of Arduino mega 2560, NodeMCU, vibration sensors, current sensors, water pressure sensors, humidity sensors, temperature sensors, dust sensors, and voltage sensors as mentioned in Table 3. These components are interconnected together, and the readings are displayed in the dashboard as well as in the simulation module.Fig. 10. presents the simulation module of the proposed BMS system. The NodeMCU communicates/transfers the readings collected by analog sensors to the dashboard through the transmitter and the receiver pin terminals i.e., TX and RX. The vibration sensor (SW-420) senses if there is a high or low vibration in the place and communicates with the dashboard through the NodeMCU. It is connected to a logic state switch which sends a signal of zeros and ones. If the signal is zero, no vibration will be detected and if the signal is logic 1,the vibration will be detected. Humidity and temperature sensors (DH22) deliver the humidity and temperature readings to the NodeMCU. The current sensor (ACS712) sends the reading of the loads' current to the NodeMCU and is displayed in the dashboard. The current readings are taken from different wires in the buildings to monitor the energy state of the building. The water pressure sensor (BMP180) senses the water pressure and sends the readings to NodeMCU. The pressure readings give us an idea about the water level in the tanks. The voltage sensor (ZMPT101B) senses the voltage in the wires and reports to NodeMCU. In the simulation module, the sensed voltage was air conditioner voltage. Dust sensor (GP2Y1010U0F) is an optical dust sensor that measures the dust level by using lenses and it can sense the dust level in the whole room, i.e., existing BMS systems do not provide this feature. The sensing module will be placed in each room in the building and all rooms in the building will report findings to the dashboard. With this method, we can predict any unusual phenomena and take actions accordingly before the occurrence of any emergency as well as monitor the energy behavior of the whole building.

For energy management, Fig. 10., also shows two lightning units, i.e., 60 W bulbs, which have been illuminated with and without automation. The bulb used without automation consumes 60W, and the bulb used with automation was illuminated at 85 percent working capacity, i.e., intensity, with a set value of operating at 51 watts, i.e., saving 9 W. This intensity does not compromise the comfort of the consumer either it affects the lighting of the room as it is providing a reasonable brightness. Moreover, this intensified value can be adjusted by the user to any desired level, keeping in view his comfort level. Therefore, the system tunes down the wattage of one light bulb by 9W, i.e., a set value in the dashboard. Hence, if a light bulb in a room is used for 10 hours a day, the system saves around 90Wh per day with a single 60 W bulb.

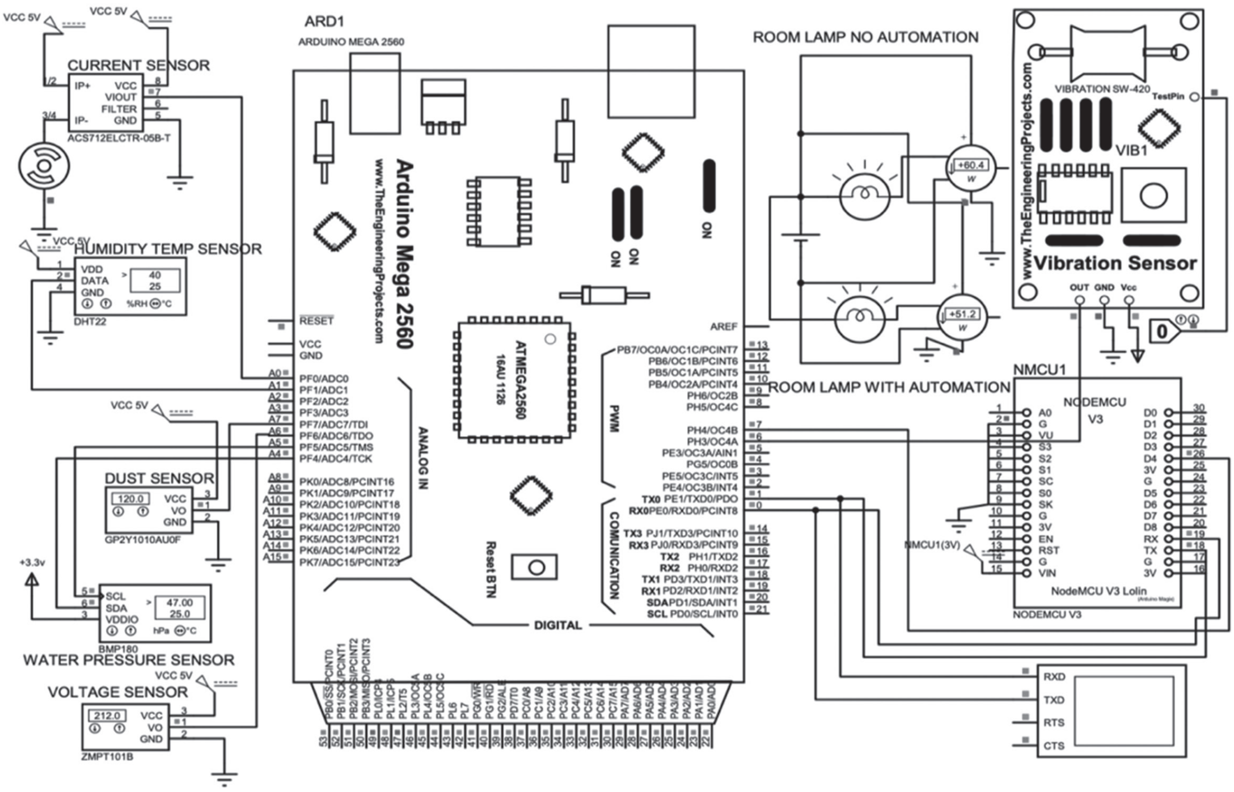

Fig. 10. Simulation module of the BMS monitoring system

Based on the same measurement and to show the impact of energy automation in our system, we have also generated random power consumption values by using Python software for twenty days as shown in Table 3.The values are generated for two scenarios, i.e., with and without automation, according to a certain power consumption range for a room in a building. The power consumption values of a room without automation are randomized in the range of 20,000-24,000 Wh per day, which is generally a power consumption of a room in residential buildings taking into account lights, air conditioning, etc. On the other hand, the power consumption with automation is set in the range of 17,000-21,000 Wh per day, i.e., a reduction of 3,000 Wh per day. This value is chosen because we can save up to 3060 W in one day in a single room, if there are four 60 W bulbs and a 1200 W air conditioner which are used for 15 hours/day at a working capacity of 85 percent, without compromising the comfort of the room. However, other multiple factors can affect the expected reduced value such as the nature of the building, daily usage, seasons, number of appliances, etc. For example, the actual power consumption of day 9 is 23,964 Wh without automation. Now, if the user sets the limit to 20,000 Wh in the dashboard, the system will try to tune down the power as much as possible to reduce up to 3,964 Wh, but it is only able to curtail 2,516 Wh. This is due to the reason that the user also specified different working capacities, i.e., intensity, of different appliances according to the comfort level of the room and the system did not comprise on the comfort of the room. Table 3 represents the simulating results for the proposed BMS system indicating the amount of power consumed with and without automation along with energy-saving. The table clearly shows that the power consumption with automation is always less than the power consumption without automation and there is always energy savings every day ranging from 1091Wh (Min) to 2651Wh (Max). This energy-saving can be further enhanced/adjusted depending on the end-user requirement and room comfort level and it is completely automated by the system. Fig. 11. shows the graphical representation of the Table 3 values, i.e., power comparison with and without automation, and energy saved for every day by using automation.

Table 3. Simulation of the energy consumption with and without automation

Days	Room Power Consumption Without Automation (Wh)	Room Power Consumption with Automation (Wh)	Energy Saved (Wh)
1	21058	19458	1600
2	22264	20156	2108
3	20077	17532	2545
4	21247	20016	1231
5	21228	20377	851
6	22843	20252	2591

7	22374	19846	2528
8	20498	19270	1228
9	23964	21448	2516
10	22438	20818	1620
11	23684	21646	2038
12	22700	21489	1211
13	23291	21501	1790
14	21796	19669	2127
15	20912	19119	1793
16	20909	19640	1269
17	23163	21689	1474
18	23782	21131	2651
19	20258	18919	1339
20	20184	19093	1091

Furthermore, the proposed system has a humidity control mechanism as shown in Fig. 12. that can monitor the relative humidity level in a room and maintain it in a predefined range, which is usually around 30-60%, as recommended by the United States Environmental Protection Agency [49]. Too much humidity, i.e., more than 60%, can cause mold, trap dirt, air pollution, etc. Similarly, too little humidity, i.e., less than 30%, can cause health issues like throat problems, eye irritation, etc. The proposed system measures and maintains the humidity level within the defined range, i.e., 30-60% [49]. In this way, the proposed system is capable of preventing structural damage and health problems by maintaining a balanced air quality inside buildings.

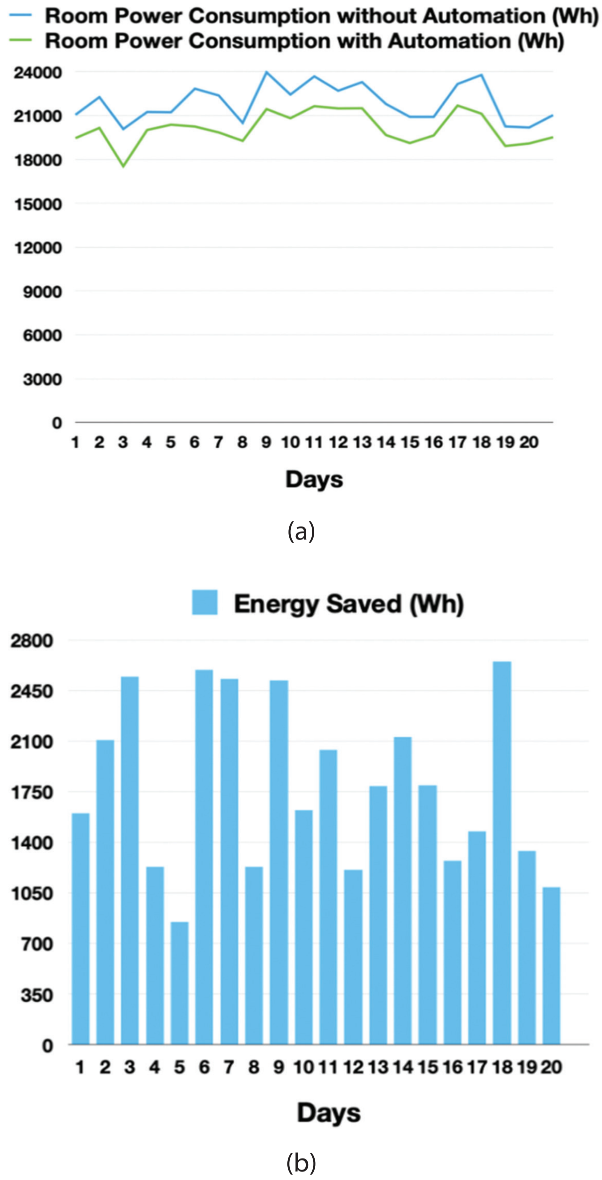

Fig. 11. (a) Power comparison with and without automation. (b) Energy saved by automation.

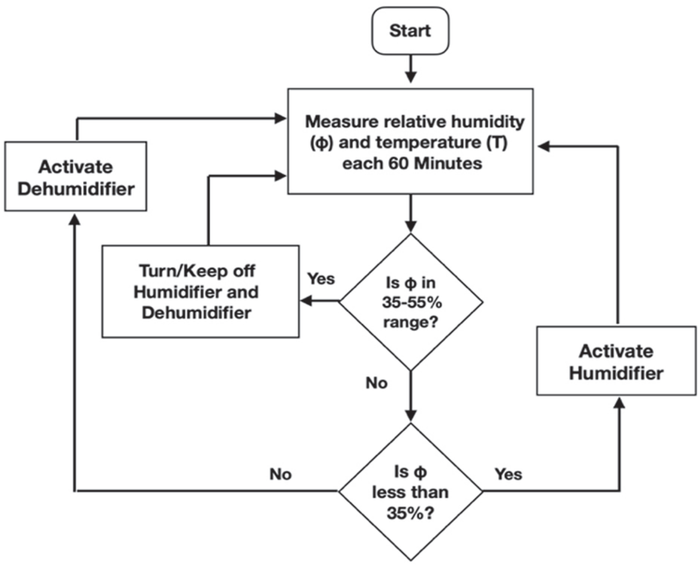

Fig. 12. Humidity control flowchart

AHT10 sensor is used to measure the temperature and relative humidity of the city of Medina, KSA. Table 4 shows the measured values for the last 24 hours, while Fig. 13. shows the graphical relationship between these two measured values. The proposed system maintains the RH value between 35-55% thresholds. Therefore, whenever the measurements go beyond these two limits as shown by red dotted lines, the system takes an automated action to keep the values within the defined range, i.e., activate humidifier if the relative humidity is less than 35%, and activate dehumidifier if the relative humidity is more than 55 %. The blue line represents the regression plot, which is based on the last 24 observations. It is used to predict the behavior of RH based on temperature, and it keeps on changing according to the new input, i.e., when measurement number 25 is recorded, the measurement number 1 is omitted to show the graph for only the last 24 observations.

Table 4. Sensors measurements (last 24 hours)

Temperature (°C)	Relative Humidity (%)	Temperature (°C)	Relative Humidity (%)
25	56	18	55
25	53	17	56
23	49	17	58
23	45	19	59
22	39	21	59
21	36	23	63
21	35	24	63
21	36	25	65
20	41	27	69
19	45	27	69
19	48	27	64
18	51	27	59

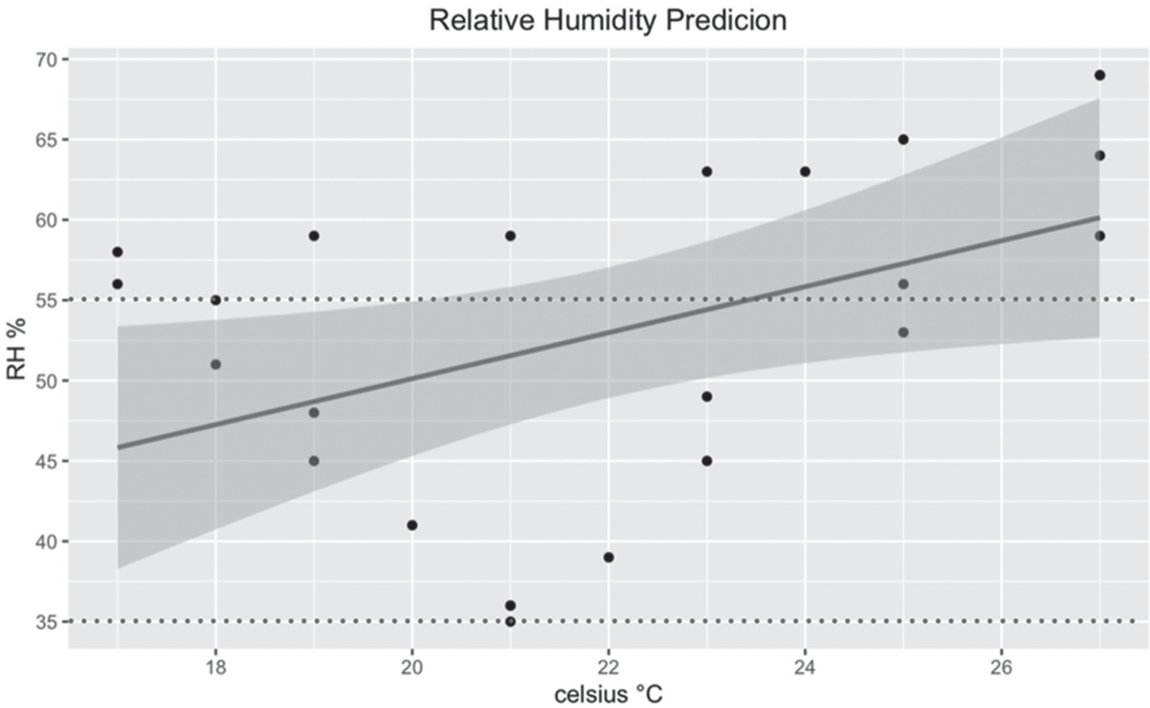

Fig. 13. Relationship between temperature & relative humidity

6. CONCLUSION

In residential/commercial buildings or large-scale facilities, many loads are installed in difficult locations other than the accessible loads and are very difficult to access for maintenance/change. Therefore, implementing BMS in buildings is very essential for controlling and monitoring all kinds of loads which can improve the overall efficiency of the facility and can also reduce operational cost, i.e., maintenance, etc. Existing IoT-based management systems generally provide only monitoring of different parameters, i.e., temperature, voltage, current, etc. The control/automation operations in these systems are generally very limited, i.e., manual performancecontrol either by increasing or decreasing the amount of output for each load or switching these loads on/off, etc. Similarly, these systems do not provide a complete understanding of the operating loads' states and conditions, i.e., machine health, facility management options, etc.Our primary contribution in this work is that the proposed system does not only provide a better and more comprehensive way of monitoring and controlling different kinds of parameters in residential buildings, but also provides the ability to take decisions automatically. The proposed system also provides an advanced level of safety to different loads automatically.

The architecture of the proposed system uses five layers instead of three or four layers as used by other systems to comprehensively obtain the overall process of the system. After a comprehensive review of the existing literature, the paper presents how different parameters, i.e., current, voltage, temperature, humidity, power, vibration, pressure, etc., are monitored by using the proposed system with full detail. Then, the paper describes two different kinds of automation, i.e., safety and energy-saving automation, as compared to the most existing systems which provide only a limited automation solution. With these two automation actions, the proposed system is not only able to monitor and safely control the loads but also operates the existing loads in a highly efficient manner, i.e., energy-efficient, etc.

Simulations were carried out to validate the energy management aspect of the proposed system. Simulation results show that at least 90Wh energy can be saved per day without compromising any kind of comfort of the end-user when a 60 W light bulb is used with proposed automation for 10 hours a day. This saving can be further adjusted/enhancedby the end-user depending on the user's comfort level. Moreover, simulations were also carried out in two different ways, i.e., with and without automation, etc., to further validate the energy management capability of the proposed system in a room for twenty days. Simulation results show that the proposed system used with automation is capable of providing a minimum energy efficiency of 1091 Wh to a maximum of 2651 Wh per day while keeping the comfort of the room at standard level. These results clearly show that the proposed system is not only capable of monitoring and controlling, but also provides efficient energy saving with an advanced level of automationas compared to the existing solutions, which is another contribution of this work.

Another contribution of this work is that the proposed system is also able to track and count up to 540 units (easily expandable) in any facility, i.e., buildings, warehouses, factories, etc., which further enhances the efficiency of the proposed system. The proposed system is also capable of keeping humidity levels inside a room between 35-55% thresholds by automatically activating and deactivating the humidifier. The proposed system is also capable of providing the dust level in a room as compared to existing BMSs which do not have this feature. The proposed system also provides constant feedback about the loads' state and notifies the operator in case of any unexpected behavior. In this way, the proposed system is capable of operating the loads in the best possible state which does not only increases the life of the loads but also enhances the overall efficiency of the system along with energy-saving. The proposed system can be installed in any large-scale facility, which will reduce the operational cost, i.e., electricity, etc., and also the time and effort of human monitoring.

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