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EMERGING INTERNET-OF-THINGS APPROACH IN MONITORING AND AUTOMATION OF INDUSTRIAL ENVIRONMENT

Haider Al-Kanan[1] and Ali A. Al-Azza[2]

[1] Department of Electrical Engineering, College of Engineering, University of Basrah, Basrah, Iraq, Email: haider.alkanan@uobasrah.edu.iq.

[2] Department of Electrical Engineering, College of Engineering, University of Basrah, Basrah, Iraq, Email: ali.noaman@uobasrah.edu.iq.

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ABSTRACT

The online monitoring of work environment plays significant role in contemporary industry automation by utilizing internet-of-things (IoT) for different measures, including security, operation efficiency, and proactive response. This article proposes an IoT technique to monitor the environment air temperature, humidity, and the required safety concerns such as fire alert and security access control using video recording. The system hardware consists of DHT22 sensor, smoke detector, and motion sensor which are all integrated using ESP8266 microcontroller and wireless router as access point to internet. The proposed IoT approach is developed using variable scheduler scenario for adjusting the temperature and humidity level of the environment based on particular season of the year. A GUI dashboard is implemented based on Blynk application to display the real-time sensors' readings and changing the operation status of some IoT devices. The operation and functionality of this IoT application is validated and tested inside a dedicated laboratory to mimic different environment conditions. While maintaining convenience air temperature, the proposed approach achieves 8%-14% improvement in power efficiency of the air-conditioning unit.

KEYWORDS

Automation, Blynk application, ESP8266, IoT, monitoring system.

1. INTRODUCTION

One of the most important goals in contemporary industrial automation is to decrease the need of working personnel in production process while maintaining the required production volume, increasing safety side, and making better use of industrial resources in production (Ahmed, et al, 2022, Mu, et al, 2024, Khang, et al, 2024). Furthermore, recent advances in machine automation result to better adoption of Internet-of-Things (IoT) capabilities to enhance feedback controllers, robotics function, and networks connectivity. In fact, IoT nowadays represents a key element that enables the development of industrial automation systems to achieve robust controls that helps streamline industrial systems with potential of minimum errors and inefficiencies, primarily on human side (Abdulhadi, et al, 2023, Tamilselvan, et al, 2023). By using IoT technology, industrial components such as sensors, actuators, IT gateways, electronic switches, motion controllers, bulbs, locks, ... etc. have become smart due to the ability of sharing information about their status and performance, while providing remote access control. Furthermore, IoT devices combined with cloud computing and advance data analytics tools can manage the connected devices efficiently and learn to adapt appropriately for accommodating new devices as needed (Abdulhadi, et al, 2023).

The key elements of integrated modern IoT system often consist of application-dependent human machine interface (HMI) on the user end, appropriate artificial intelligent (AI) technique for decision making, and distributed control system (DCS) in the bottom level of IoT hierarchy as depicted in Fig. 1. which has become huge driver to various industry sectors. Each level in the hierarchy exhibits certain features in terms of application functionality, complexity in both hardware and software, and implementational cost. The proposed approach in this article employs a low cost and complexity system for integrating sensors, IoT device, and open-source cloud infrastructure to create intelligent system that can detect and respond to threats in industrial environments. The proposed approach can be deployed in houses, hospitals, agriculture, and other industry applications that requires prompt response in some hazardous circumstances. For example, a smoke detection system is implemented to activate alarm notification in case of fire in the existing environment. Motion sensor is installed for controlling video recording in case of security threats. Finally, air conditioning (AC) units are instantaneously monitored using temperature and humidity sensors supported automatic remote control of cooling systems and in-door lights.

The main functionality of this IoT system is to ensure effective regulating of industrial environments, and to prevent overheating or overuse inadequate cooling resources. By leveraging these technologies, our system aims to improve safety, energy efficiency and productivity in industrial environments. This article is organized as follows: related work on this topic is described in section 2, the study's methodology is described in Section 3, while Section 4 presents the system operation including the validation results of the proposed system. The conclusion is drawn in Section 5 with some final remarks and an exploration of topics for protentional future research.

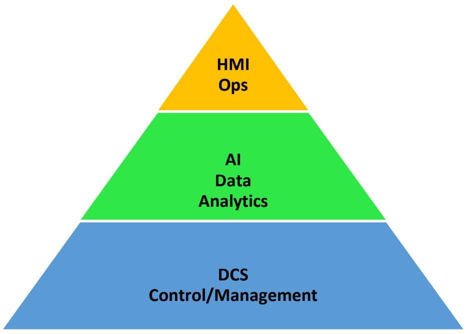

Fig. 1. Process hierarchy layers of smart IoT unified system.

2. IOT IMPLEMENTATION

An efficient implementation of IoT-based industrial automation is ongoing research goal which gained significant attention over the past five years. The desired improvement includes low complexity and energy consumption, as well as high productivity in performance and security measures subject to the deployed application (Chen, et al, 2022). Many studies have focused on overcoming the challenges of integrating the existing traditional infrastructure with the state-of-the-art IoT applications. For instance, the authors in (Khang, et al, 2024) explore the use of IoT in smart agriculture, where sensors and actuators are used to automate the existing irrigation, pest control, and other agricultural activities for improving crop productivity and labor costs. In manufacturing industry, IoT-based automation has been developed by collecting data of the machine operation for post-processing to enhance production processes and quality control. Other studies have explored the challenges of data security in IoT-enabled industrial automation and proposed a framework for secure data transmission. The presented approaches in literature showed that integrating modern IoT technology with traditional existing industry automation systems poses significant implementation challenges due to several limitations which require special middleware-based approach for integration (Almazroi, et al, 2024). Furthermore, recent area of research has focused on merging IoT-based automation with predication capabilities, involving AI and machine learning technologies, as well as integrating a cloud computing to optimize industrial processes and reduce energy consumption (Al-Kanan & Alzuhairi, 2024, Gupta, et al, 2019, Devi, et al, 2020). In summary, the literature contributions of IoT-based industrial automation showed significant advancement in mitigating the challenges for optimal improvement in efficiency, productivity, and safety in industrial environments. The key elements and requirement of typical IoT system must be analyzed carefully to meet both the business and technical goals. The core elements of most IoT systems are summarized as follows:

1. Connected Devices/Sensors: Selecting appropriate devices is an important initial stage in IoT system design which specifies the overall system performance including the accuracy of the acquired data and power efficiency. In other words, using an efficient hardware including robust sensors that monitor machine operations and report any abnormalities/warning signal, often resulting in greater operation efficiency and less waste in energy consumption.

2. Data Collection: Once the process has been identified, the next step is to identify relevant data that needs to be collected to automate the process. For instance, pressure, temperature, water content, noise, light, and vibration are common examples of data acquisition. Various Statistical methods play an important role in classifying, cleaning, and identifying the appropriate data. For example, the correlation between two different quantities can be used to improve the accuracy and clean-up process of the acquired data.

3. Device Communications: Wireless solutions, such as Wi-Fi which is widely used technique in a medium range IoT communication of connecting sensors, machines, and actuators to certain microcontroller system (Barznji, A., and Jalal A., 2021). This option determines how the information is sent and processed from one device to another so that all components can work together. In addition, each IoT scenario requires a different set of protocols depending on the deployed application.

4. Energy Efficiency: Developing energy efficient IoT system is a crucial concern, given the deployment of many connected devices and their dependence on limited power resources, such as limited battery life. This concern stems from the reliance of IoT devices on limited power resources, coupled with their increasing use in diverse applications. Hence, implementing dynamic energy management strategy based on real-time conditions, such as sleep/wake mechanism optimization is one of the most effective approaches in modern IoT deployment. In particular, the proposed IoT system in this work uses different date scheduler scenario for controlling the operation of the air conditioning unit based on four seasons.

5. Industrial Processes: Several on-site industry surveys are required to make a clear plan and identify the industrial processes that need to be automated and integrated with IoT instruments. This could be a manufacturing process, supply chain management or any other process that needs to be monitored and controlled based on IoT technology.

6. Storage/Cloud Infrastructure: The acquired data from IoT devices, such as sensors must be

stored temporary or permanently for post-processing using cloud infrastructure. Therefore, a cloud-based IoT system is widely used nowadays to store and process large amounts of data, and provide real-time insights, as well as it provides convenience access control capabilities (H, Sivalingan, 2024).

7. Software Applications: Most of IoT applications are developed to provide real-time monitoring and controlling industrial processes. Several programming languages are used to enable HMI functionality including remote access capabilities, allowing authorized personnel to monitor, manage, and control the industrial processes.

8. Testing and Validation: Testing and system validation of an efficient IoT system requires several sets and operation procedure to ensure that it operates smoothly as expected. All the system components and functionalities must be validated such as the deployed sensors and devices under different circumstances, cloud infrastructure and software applications, as well as system capabilities and response to critical situations.

3. PROPOSED IOT APPROACH

The proposed IoT architecture in this work has been implemented to mimic automated industrial processes using both manual and automatic response to certain environment conditions. In particular, this system is deployed to monitor air temperature, humidity, smoking, and video recording based on motion detection. The IoT system has the capabilities of remote access control through internet based on cloud technology as depicted in Fig. 2. The IoT system consists of microcontroller with transceiver chip, cloud Blynk server, and different types of sensors which are sending instantaneous readings to the microcontroller. Hence, if a smoke is detected, temperature/humidity increased, or motion detected near access gate, this trigger the Blynk server for remote monitoring and control.

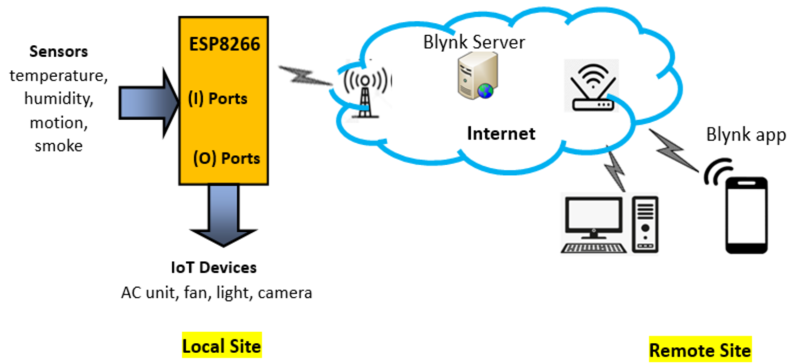

Fig. 2. Proposed IoT system architecture.

The controller board ESP8266 is connected to Blynk cloud via internet access point based on Wi-Fi communication protocol. The microcontroller is programmed via Arduino IDE to read the sensor data and transmit it periodically to the Blynk server. In addition, the Blynk application and interface have been configured to authenticate, view, and control sensors remotely. The measurement of the deployed sensos (temperature, humidity, and motion) are calibrated based on thermometer and hygrometer to fulfil the system requirements. The functionality of the proposed IoT approach is developed such that the sensor readings are instantaneously acquired and analyzed with respect to certain predefined thresholds. For example, when the environment temperature exceeds the threshold level (Td), a control signal is used to trigger a relay module to activate the cooling system. Similarly, a humidity level controller is configured to maintain certain condition based on a pre-set threshold level (Hd). Furthermore, the parameter of threshold level is configured periodically based on annual seasons using multiple threshold adjustment (Δ) as the environment conditions (temperature and humidity) varies significantly with respect to the season.

Fig. 3 illustrates the dynamic operation of the proposed scheduler in the deployed IoT approach assuming the weather conditions almost steady during the spring and autumn seasons. Hence, the threshold of both the temperature and humidity changes dramatically every 90 days in the pattern shown in Fig. 4 depending on the particular season. The advantage of this scheduler approach is to improve the overall power efficiency of cooling system by mitigating unnecessary usage.

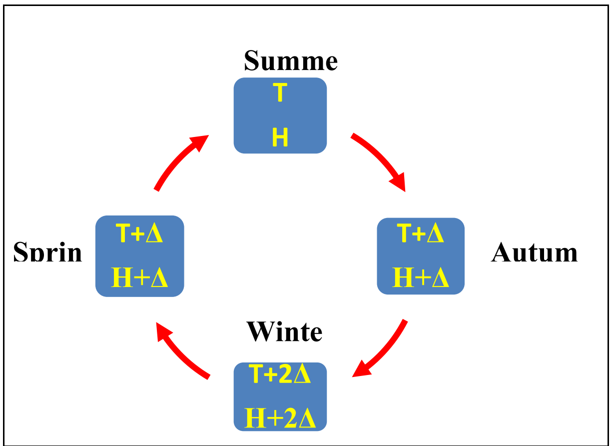

Fig. 3. Seasonal scheduler scenario of the proposed IoT approach.

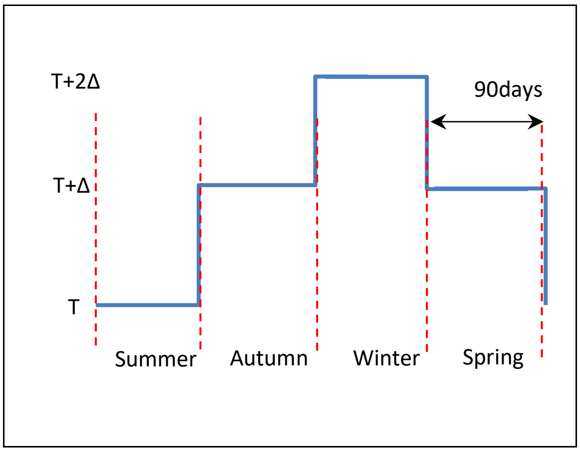

Fig. 4. Adjustment of threshold level for temperature and humidity control.

The proposed monitoring approach includes a smoke detection function which is developed to activate an alarm notification in presence of hazardous smoke or fire. Finally, a light and ventilation (i.e fan in this work) system is integrated in our system using a toggle button on the Blynk GUI based on a remote-control option to switch them on/off. The technical specifications of the IoT instruments used in this work are summarized as follows:

3.1. Temperature/Humidity Sensor

The DHT22 is a low complexity sensor which is a widely used tool for measuring both temperature and humidity. For temperature sensing, it has operating range from -40ºC to 80ºC -/+0.5ºC and humidity measurement range of 0-100% with accuracy 2-5% and a response time of 6 to 30 seconds, making the device reasonable across various climates and environments. The DHT22 transmits data in a digital format with high accuracy, reducing noise and making it easier to interface with microcontrollers. These features in addition to low power consumption make the DHT22 a powerful instrument for IoT systems that require instantaneous environment monitoring.

3.2. Motion Sensor

The passive infrared (PIR) device is an electronic sensor that is widely used in motion detection, such as applications of automatically activated lighting and protection systems that measure the emit infrared light within its range of vision. The infrared sensor is placed in a sealed metal housing for improved noise/temperature/humidity resistance. In addition, the sensor contains a window made of infrared transmitting material for detecting the thermal radiation of human body. The PIR Consumes very little power, enabling use in low-power IoT applications that requires a reasonable detection range (typically 6–10 meters), suitable for most indoor and outdoor applications. In addition, the PIR is a low cost and simple to implement with minimal setup requirements, making the PIR is preferred instrument in security systems of industrial automation.

3.3. Microcontroller board

The ESP8266 is a system-on-chip (SoC) board developed by Espressif systems based on a 32-bit RISC CPU with Tensilica Xtensa LX106 processor. It includes other system capabilities, such as analog-to-digital conversion, serial peripheral interface, and pulse width modulation (PWM). Furthermore, it has a built-in Wi-Fi (802.11b/g/n) which is employed in this work to communicate with internet access point (Hasan, A., 2022). The general-purpose input/output (GPIO) ports are used for interface with IoT sensors and devices. The ESP8266 board is equipped with a firmware program written in C++ language that handles all connections to the sensor including the header files for integration, processes sensor data and communicates with the IoT devices, and finally it can exchange IoT data with wireless router.

3.4. IoT Communication

Current IoT trends focus on transferring data to a centralized cloud platform managed by IT professionals and accessible by anyone with right credentials and internet connection. The power of cloud computing provides the storage and processing capabilities needed to manage massive sensor data. The Blynk cloud platform provides a user-friendly interface used in this work to implement the assigned tokens of online and real-time monitoring/control dashboard. The ESP8266 board has the Wi-Fi capability which communicates with Wi-Fi router as a station node and can periodically transmit sensor data directly to the Blynk cloud via the internet. The Blynk application is designed with several security protocols and encryption methods to ensure data integrity and preventing unauthorized access. All data transferred between the Blynk mobile app and the Blynk cloud server is encrypted using TLS (Transport Layer Security) protocols, preventing eavesdropping or man-in-the-middle attacks. In addition to the encrypted communication between the ESP8266 board and the Blynk server, the acquired stored data in the Blynk cloud is encrypted using AES-256 algorithm. Furthermore, the Blynk application enables administrators to configure role-based access, limiting certain actions to authorized users only. This feature helps in managing access permissions and applying restriction on sensitive operation. By integrating these robust security protocols and encryption mechanisms, the Blynk application ensures integrity, confidentiality, and availability of data within its ecosystem.

4. RESULTS AND DISCUSSIONS

The ESP8266 board is configured to receive sensor data through GPIO interface via wire connections because the installed sensors are located onsite near the controller board. On the other hand, the ESP8266 board is communicated to wireless network access point using wireless router which assigns IP address upon successful connection using the SSID and password. The ESP8266 board is programmed in C++ language and compiled using Arduino IDE, and finally the compiled file is uploaded to a memory of ESP8266 board. Once the prototype system is deployed during the configuration phase, a live data will be monitored on the cloud console based on http protocol. The operation procedure in this work is programmed based on the flow chart as depicted in Fig. 5, which describes the IoT system integration using four independent sensors. When the temperature reading increases beyond the predefined value (T_d=20^{o}C and Δ=3.5%), it will send an alert and automatically switching the cooling system on, otherwise it will continuously monitor the environment temperature.

Similarly, the humidity threshold level (H_d=35%) is set for controlling the operation of the dehumidifier machine to maintain adequate and desired level of humidity especially in certain industry application, such as in semiconductor manufacturing facilities. The GUI is designed using Blynk application as depicted in Fig. 6 which visualizes and controls all the IoT components. this application displays real-time readings of both temperature and humidity conditions in various conditions of the environment. The control section of the GUI includes two control manual switches for the fan and light, allowing convenient remote control to turn these devices on/off.

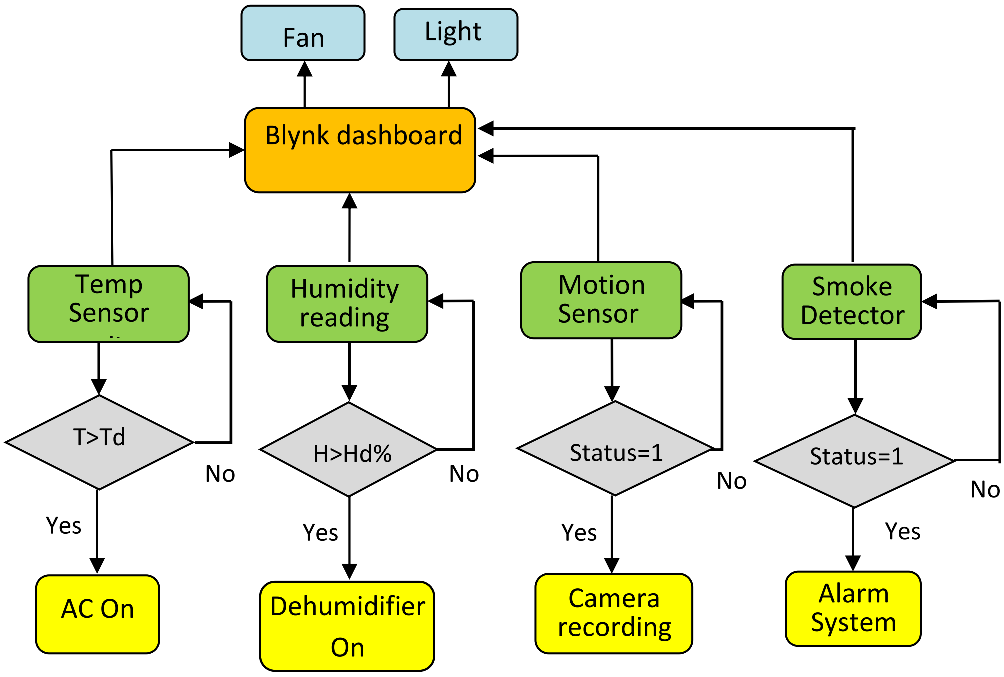

Fig. 5. Flow chart of IoT components for monitoring and control approach.

An extensive testing of the entire system is performed to evaluate all the system components including the communication with Blynk server, sensors reading accuracy, and control response of various triggers. In addition, the functionality of automation, such as motion detection, temperature regulation, smoke detection, and remote light control have been verified. For example, the smoke detector is activated using a simulated smoke near the sensor which triggers the ESP8266 controller to communicate with Blynk server that pop up alert message on the monitoring GUI and change the smoke detector status from logic 0 to logic 1 as depicted in Fig.7.

The measurement accuracy of DHT22 readings is validated based on statistical comparison of the obtained results with respect to actual conditions measurements using thermometer as depicted in Fig. 8 for four seasons during the year based on Basra/Iraq environment conditions. These results are obtained by adjusting the environment temperature and humidity inside a dedicated lab that is equipped with cooling and heating system to mimic real-scenario for four seasons similar to weather conditions in Basra/Iraq. The obtained results in Fig. 8 as well as the humidity readings in Fig. 9 are validated over two hours period which exhibit consistence trendline with respect to the time of around ∓1.5% errors which is an adequate range in this application of monitoring the site conditions. Validating sensor readings and system performance beyond lab conditions is crucial for ensuring reliability and applicability in real-world industrial environments. Hence, the IoT system is tested under different dynamic conditions and using suitable temperature/humidity threshold quantity for each test scenario. In addition, the operator can adjust and control the level of the threshold to improve the system performance under varying temperatures and humidity levels including harsh industry environment. By combining field conditions and the sensor readings, the thresholds can be fine-tuned to meet the required system performance in terms of accuracy, reliability, and robustness, making the IoT system suitable for real-world deployment for different climate region.

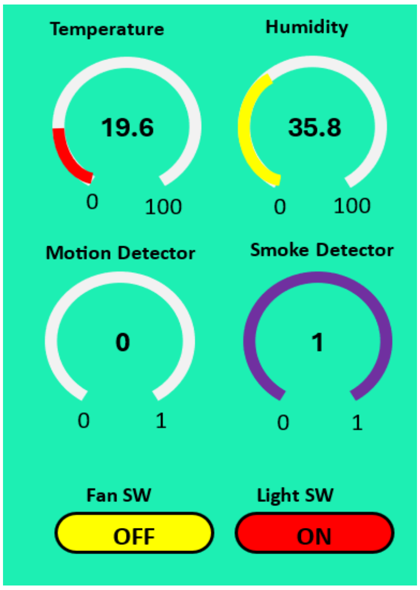

Fig. 6. GUI implementation for IoT control dashboard.

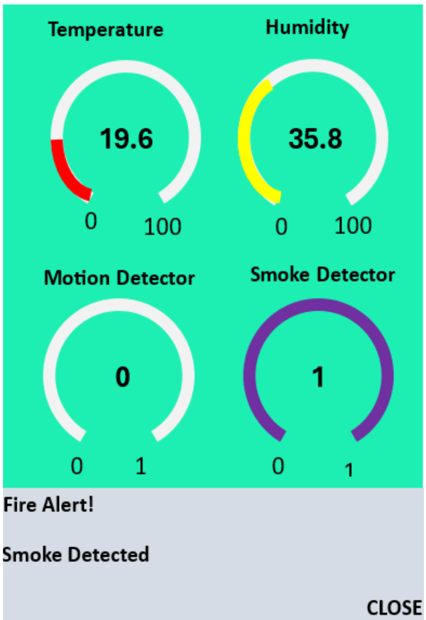

Fig. 7. Testing scenario for smoke detection and alert.

Fig. 8. The measured temperature and thermometer reading in different seasons.

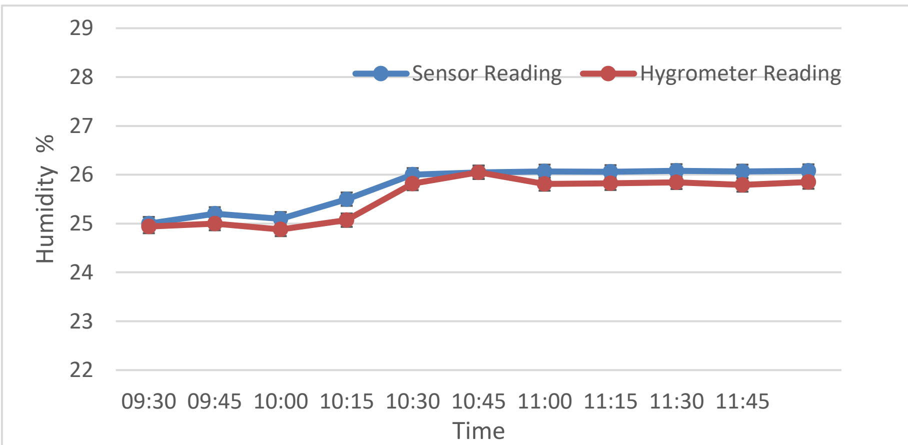

Fig. 9. The measured humidity and hygrometer reading.

By simulating different environment conditions in a dedicated lab, the electricity usage of the AC unit is monitored and calculated during 5 hours test period for two scenarios. The first test case is a normal operation without proposed threshold control and the second test is performed based on the proposed different threshold limit for each season. The obtained results for each test scenario (excluding winter season due to normally cold weather based on tested location) are depicted in Table 1 which illustrates the utilization percentage using the following expression:

$$Utilization\% = \frac{(AC\ usage_{normal\ case}) - (AC\ usage_{proposed\ case})}{Test\ duration} \times 100$$

Table 1 Compared operational results of different test scenarios.

Season	AC Duration of Operation (Normal case) (hours)	AC Duration of Operation (Proposed case) (hours)	Utilization
Spring	3.56	2.84	14.4%
Summer	4.21	3.77	8.8%
Autumn	3.38	2.72	13.2%

The enhancement in AC usage is obtained due to the performed temperature and humidity thresholding that controls the on/off status based on the operation date (season). The obtained results in Table 1 are calculated based on the lab conditions to maintain average convenience temperature. Hence, the applied thresholding technique in this work improves the AC operation and decreasing the power consumption while maintaining convenience temperature range. In fact, this method results in more than 14% improvement in power usage of AC unit during spring season which is an adequate when deploying the same approach on large space that has multiple AC units.

Finally, the motion sensor is configured as logic 0 (no movement) /1 (movement) for security protection to enable video recording on the monitored site via CCTV camera that has integrated with storage hard-disk. The camera is located on the corner above the access door to test this scenario, such that when a walking person trying to enter the field, the motion sensor trigger the controller to activate the camera for real-time monitoring the zone as well as a message is pop up on the Blynk GUI posting alert to the end user as depicted in Fig. 10.

The proposed approach has the features to be expanded and configured easily for alert as well as recording the site conditions. Future enhancements might be included by integrating additional sensors, implementing predictive analytics, or expanding control functionality. The ability to monitor, control, and real-time display support improving the efficiency, safety, and convenience in industrial environments.

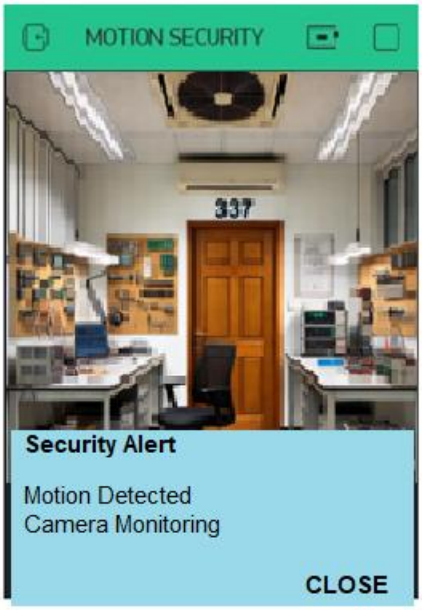

Fig. 10. Testing scenario for site monitoring based on camera and motion sensor.

5. CONCLUSIONS

An IoT technique has been presented in this article with emphasizing on industrial automation including hazard detection and controlling the environment temperature/humidity. The proposed approach employs different sensors to detect smoke, movement, temperature, and humidity variation in the environment. The IoT system includes a smoke detection to send alert notification on the Blynk dashboard that is used to monitor particular site remotely. Motion sensor has improved the security measures by enabling video recording of the site using CCTV camera. Temperature and humidity sensors are used in this approach which allows monitoring and controlling fan and cooling system that regulate the environment air and improving the operational efficiency while reducing energy costs. A laboratory set-up illustrates an efficient remote control including real-time data acquisition and response to minimize the risk of an accident. The usage of AC unit has been improved by 8%-14% due to the proposed threshold scenario to adjust the operation efficiently.

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