World Journal of Advanced Engineering Technology and Sciences

eISSN: 2582-8266

Cross Ref DOI: 10.30574/wjaets

Journal homepage: https://wjaets.com/

WJAETS

(Review Article)

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Green Edge: Harnessing situational awareness for sustainable systems

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World Journal of Advanced Engineering Technology and Sciences, 2024, 13(01), 699–705

Publication history: Received on 18 August 2024; revised on 01 October 2024; accepted on 03 October 2024

Article DOI: https://doi.org/10.30574/wjaets.2024.13.1.0454

Abstract

Green computing and Building Management Systems (BMS)are closely related through their shared goal of improving energy efficiency and reducing environmental impact. Field controllers that connect with the sensors and actuators at the field level act as an interface between field devices and enterprise applications. Data transfer, protocol conversion, data processing, computing, and control actuators based on predefined logic are the functions of the field controllers. Fast response time is one of the crucial parameters of these field controllers hence reducing the load on these field controllers by enabling Edge computing functionality is very much required. Maharudrayya Nandimath and others [16] in their "Edge Computing in IBMS (Integrated Building Management Systems). (2024 International Conference on Computer Communication and Informatics (iccci. in)) the paper suggested many of the measures to reduce the load on these field controllers. Building Management Systems are essential for optimizing the operation of modern buildings, ensuring comfort, safety, and energy efficiency. By integrating advanced technologies such as Situation Awareness (SA) and Artificial Intelligence (AI), BMS can be significantly enhanced to provide real-time monitoring, predictive maintenance, and intelligent decision-making. This paper explores the potential of combining SA and AI with BMS, leveraging insights from recent research on industrial processes, IoT cloud-edge continuum, and smart cities. The proposed system architecture includes feedback loops and contextual awareness, aiming to improve building operations and reduce energy consumption, thereby supporting global sustainability goals.

Keywords: Situational Awareness (SA); Edge Computing; Building Management Systems (BMS); Green Computing. Integrated Building Management Systems (IBMS); Energy Efficiency; Sustainability

1. Introduction

Green computing involves designing, manufacturing, using, and disposing of computers and related systems efficiently and with minimal environmental impact. In Building Management Systems (BMS), edge controllers collect data from sensors and control actuators. By leveraging edge computing, which is a part of green computing, BMS can process data locally, reducing energy consumption and latency, and enhancing overall system efficiency. This integration promotes sustainable building operations and energy conservation. Building Management Systems (BMS) play a crucial role in managing the various subsystems within a building, such as heating, ventilation, air conditioning (HVAC), lighting, and security. Traditional BMS rely on predefined rules and schedules, which may not be optimal for dynamic and complex environments. The integration of Situation Awareness (SA) and Artificial Intelligence (AI) can transform BMS into intelligent systems capable of real-time monitoring, predictive maintenance, and adaptive control. This paper aims to explore the potential of combining SA and AI with BMS, leveraging insights from recent research on industrial processes, IoT cloud-edge continuum, and smart cities. The paper "Real-time Situation Awareness of Industrial Process based on Deep Learning at the Edge Server" [1] provides a framework for achieving real-time SA using deep learning and edge computing. This approach can be directly applied to BMS to enhance real-time monitoring and predictive maintenance. By processing data locally at the edge, latency is reduced, and response times are improved, enabling more effective

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management of building systems. The paper "Leveraging Context-awareness to Better Support the IoT Cloud-Edge Continuum" [2] emphasizes the importance of context-aware decision-making in IoT systems. This concept can be extended to BMS, where context information such as weather conditions, occupancy patterns, and user preferences can be used to optimize building operations. By integrating edge and cloud resources, the system can achieve a balance between performance and latency, ensuring efficient and effective management of building systems. The paper "Empowering Smart Cities: A Comprehensive Edge Computing Framework for Enhanced IoT Situation Awareness" [3] discusses the role of edge computing in smart cities. The principles outlined in this paper can be applied to BMS to enable real-time data processing and reduce latency. By processing data closer to the source, the system can provide timely and accurate insights, improving the overall efficiency and effectiveness of building operations. The paper "Situation Awareness in AI-based Technologies and Multimodal Systems: Architectures, Challenges, and Applications" [4] provides an overview of how AI and multimodal methods can be used to build and enhance SA. By combining data from various sources, the system can create a comprehensive understanding of the building's state, leading to better decision-making and improved performance. The challenges and future directions outlined in this paper highlight the need for continued innovation in SA and AI technologies. The paper "A Situation Awareness Perspective on Human-AI Interaction: Tensions and Opportunities" [5] explores the role of SA in human-AI interaction. By designing AI systems that enhance human performance and decision-making, the user experience and effectiveness of BMS can be significantly improved. The tensions and opportunities identified in this paper provide valuable insights into the design and implementation of AI-driven BMS. Edge Computing in IBMS (Integrated Building Management Systems) by Maharudrayya Nandimath and Beena BM focuses necessity of reducing the load on Field controllers and also advises the measures to reduce the same with CoV [16]. Identifying the gaps challenges, and advantages of Situational Awareness and AI to the Building Management System (BMS) as a whole is necessary.

2. Research Problem and Related Work

The global Building Management System (BMS) market is experiencing significant growth due to the increasing adoption of these systems to manage large, complex infrastructures. The market is projected to grow at a compound annual growth rate (CAGR) of 14.64% from 2023 to 2030, reaching approximately $48.79 billion by 2030[17]. This growth is driven by the need for energy efficiency, sustainability, and the integration of advanced technologies like IoT and AI in building management [17][18]. The industry's expansion is also fueled by the rising demand for smart buildings and the implementation of stringent regulations for energy conservation [18]. As more organizations recognize the benefits of BMS in optimizing building operations and reducing operational costs, the adoption of these systems is expected to continue growing globally. Understanding the Importance of Building Management Systems and the growing adoption rate, it is essential to improve the overall system performance to meet the objective of energy and operation efficiency developing a framework for enhancing Edge computing by adding situational awareness (SA) and Artificial Intelligence (AI) into the architecture. Currently, there are limitations in Building Management Systems at both levels which are explained below.

2.1. Field Level

At the field level, multiple sensors are connected to field controllers which are linked to enterprise applications that may be hosted on-premise/cloud servers. The field controllers have limited Edge functionalities, as many custom logics are developed based on the requirements to control the actuators and also data requests. There will often be delays and controller hang issues because of the controllers' limited processing capabilities. There is a need to add intelligence to prioritize actions based on situations/contexts and provide real-time information to meet user requirements.

2.2. Enterprise software/application level

The major focus of the software/application is to collect the data from field controllers and to notify the alert events further to the users through its console. This shall be hosted either on-premise or on the cloud. However, due to the advancement in cloud technologies and considering the future expansion, most of the Building Management Software/applications are hosted on the cloud. Due to this advancement, complex logics are moved to the cloud, and field controllers have to be always/frequently connected to Enterprise software/applications. But these frequent connections consume more energy inclusive of cloud infra (switches, data center, etc.) and consume more bandwidth. Enabling EDGE functionality in field controllers became crucial and necessary to reduce energy consumption. Situational Awareness and AI can bring local intelligence to the field controllers and reduce the frequency of connectivity/dependency on Enterprise software/applications thus enabling EDGE intelligence which will serve the need for real-time data availability closer to the customer. Additionally, traditional Building Management Systems (BMS) face several limitations that hinder their effectiveness in modern, dynamic environments because of the following limitations.

- **High Costs**: BMS installation and maintenance are expensive, often requiring significant investment in sensors, equipment controls, and skilled labour.
- **Limited Real-time Monitoring**: Traditional BMS offer limited real-time monitoring capabilities, which can delay the identification and resolution of issues.
- **Lack of Adaptive Control**: These systems struggle with adaptive control, making it difficult to adjust to changing conditions dynamically.
- **Integration Challenges**: Traditional BMS are often built on proprietary technologies, making it challenging to integrate third-party devices or components.
- **Scalability Issues**: Expanding traditional BMS to accommodate new devices or facilities can be complex and costly.
- **Data Utilization**: The data collected by BMS is often dense and difficult to analyze, requiring dedicated personnel and additional software for meaningful insights.

Below is the block diagram of existing building management systems.

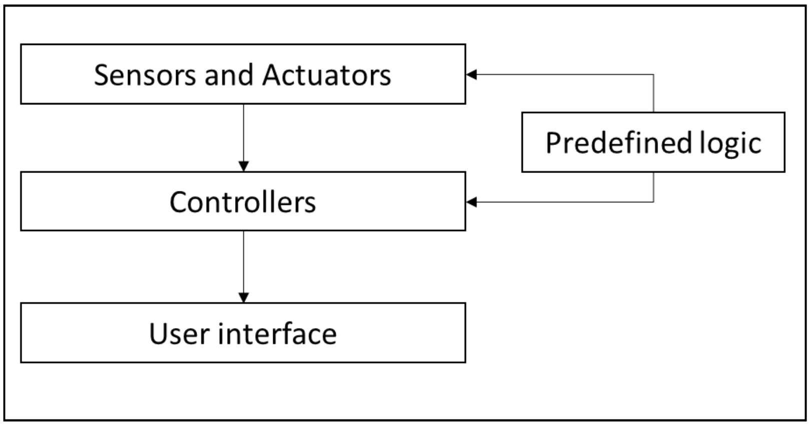

Figure 1 Existing BMS systems

The above figure (Figure 1) shows the traditional approach to the BMS system that is currently in practice. Existing BMS systems will only work based on the predefined logic and have no AI component. There will be many custom logics (schedule, set-point, alerts, and operations specific). There is no particular framework or methodology considering the limitations or specifications.

2.3. Proposed system

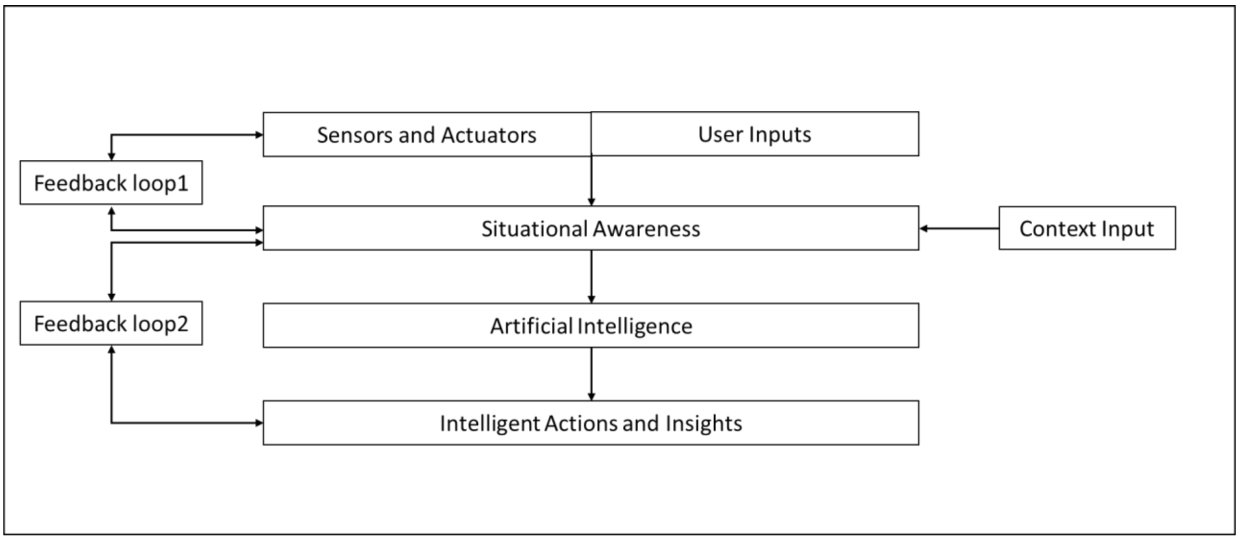

Figure 2 Proposed system

The system proposed in this paper is shown above. The proposed system has two new blocks along with feedback loops and context input. Following are the key improvements that can be realized by SA and AI. Based on the context and user inputs logics will be auto-enabled by the AI component considering the controllers' limitations (memory and processing power) and also optimizes and schedules the logics appropriately. For example, the HVAC (Heating, Ventilation, and Air-Conditioning) settings will not only consider the range of the temperature to decide the set point but also consider the user's feedback, outside temperature, and indoor temperature of the other HVAC's loading/utilization of, current loading, capacity, and status. So, these multi-inputs will not only bring operational efficiency but also achieve equipment health, lifetime, and energy efficiency.

Integrating SA and AI into BMS can address these limitations and bring significant improvements:

- **Enhanced Real-time Monitoring**: AI algorithms can analyze vast amounts of data in real-time, enabling proactive decision-making and predictive maintenance.
- **Adaptive Control**: AI-driven systems can dynamically adjust heating, cooling, lighting, and ventilation based on real-time data and occupant preferences.
- **Improved Integration**: SA and AI can facilitate the integration of various IoT devices and systems, enhancing interoperability and flexibility.
- **Scalability**: AI and edge computing enable scalable solutions that can easily accommodate new devices and facilities.
- **Efficient Data Utilization**: AI can automate data analysis, providing actionable insights and reducing the need for manual intervention.
- **Energy Efficiency**: By optimizing the operation of building systems, AI can significantly reduce energy consumption and enable Green Computing.

Situational Awareness (SA) clubbed with Artificial Intelligence (AI) shall bring the following improvements to the Building Management System.

- **Real-time Situation Awareness in Industrial Processes**: The paper discusses the use of deep learning and edge computing to achieve real-time SA, which can be applied to BMS for enhanced monitoring and predictive maintenance.
- **Context-awareness in IoT Cloud-Edge Continuum**: This research highlights the importance of context-aware decision-making, which can improve the adaptability and efficiency of BMS.
- **Empowering Smart Cities with Edge Computing**: The role of edge computing in smart cities can be extended to BMS, enabling real-time data processing and reducing latency.
- **Situation Awareness in AI-based Technologies and Multimodal Systems**: The use of AI for data fusion and prediction can enhance the situational awareness of BMS, leading to better decision-making.
- **Human-AI Interaction and Situation Awareness**: Designing AI systems that enhance human performance can improve the user experience and effectiveness of BMS.

Below is the proposed pseudo-code for the field controller followed by the flow chart

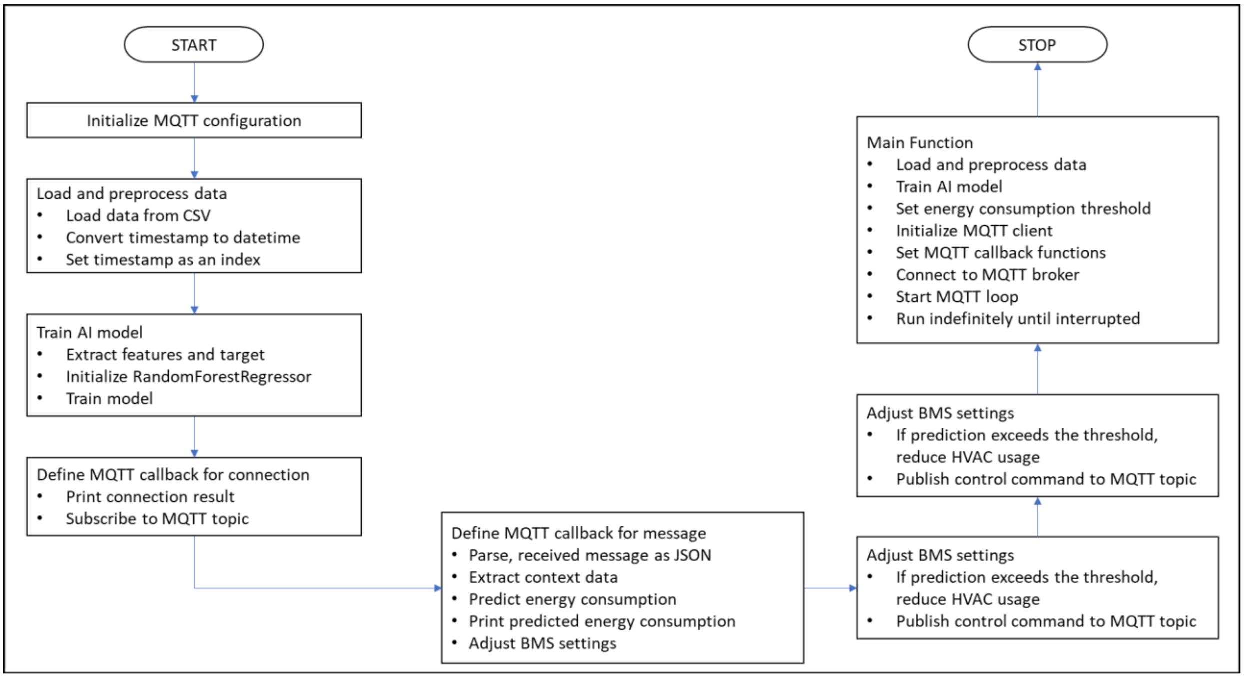

Figure 3 Flow chart of the proposed program implementing the proposed architecture

The above flow chart exemplifies how situational awareness, Artificial intelligence, and Context input for Situational awareness have been provided.

2.3.1. Situation Awareness (SA)

- **Real-time Monitoring**: The system continuously monitors environmental conditions (temperature, humidity, occupancy, weather) and uses this data to maintain an up-to-date understanding of the building's state.

2.3.2. Artificial Intelligence (AI)

- **Predictive Maintenance and Adaptive Control**: The AI model predicts energy consumption using real-time context data. This prediction helps in making informed decisions to optimize building operations.

2.3.3. Feedback Loops

- **Continuous Improvement**: The system uses feedback loops to adjust settings based on predictions. For example, if predicted energy consumption is high, the system reduces HVAC usage to save energy.

2.3.4. Context-aware Decision Making:

- **Informed Decisions**: The system considers contextual information (e.g., weather conditions, occupancy patterns) to make more informed and effective decisions about building operations.

3. Research Relevancy

The integration of SA and AI into BMS is highly relevant for several reasons:

- **Energy Efficiency**: Buildings account for a significant portion of global energy consumption. By optimizing the operation of building systems, the proposed BMS can significantly reduce energy consumption, contributing to global efforts to combat climate change.
- **Operational Effectiveness**: The proposed BMS can improve operational effectiveness by providing real-time monitoring, predictive maintenance, and adaptive control. This ensures that building systems operate optimally, reducing downtime and maintenance costs.
- **Enhanced Comfort and Safety**: By providing real-time monitoring and predictive maintenance, the proposed BMS ensures a comfortable and safe environment for building occupants.

- **Scalability and Reliability**: The proposed BMS can scale to accommodate the growing number of IoT devices in buildings, ensuring reliable operation even in complex and dynamic environments.

3.1. Research Approach and Key Contributions

The proposed system architecture includes the following components:

- **User Inputs**: Collecting data from building occupants and facility managers to understand their needs and preferences.
- **Sensors and Actuators**: Deploying a network of sensors to monitor environmental conditions (e.g., temperature, humidity, occupancy) and actuators to control building systems (e.g., HVAC, lighting).
- **Situational Awareness**: Implementing SA to process sensor data and create a comprehensive understanding of the building's state.
- **Artificial Intelligence**: Using AI algorithms to analyse SA data, predict potential issues, and optimize building operations.
- **Intelligent Actions and Insights**: Providing actionable insights and automated control to improve building performance and energy efficiency.

To enhance the proposed system, feedback loops, and contextual awareness are integrated:

- **Feedback Loops**: Adding feedback mechanisms to continuously update SA and AI models based on the outcomes of intelligent actions. This ensures that the system adapts to changing conditions and improves over time.
- **Contextual Awareness**: Incorporating context information (e.g., weather conditions, occupancy patterns) to make more informed decisions about building operations.

3.2. Linking to Sustainability Goals

The proposed system aligns with several sustainability goals, particularly those related to energy efficiency and environmental impact:

- **Energy Efficiency**: By optimizing the operation of building systems, the proposed BMS can significantly reduce energy consumption, contributing to global efforts to combat climate change.
- **Reduced Carbon Footprint**: Improved energy efficiency leads to lower greenhouse gas emissions, supporting sustainability goals.
- **Enhanced Comfort and Safety**: By providing real-time monitoring and predictive maintenance, the system ensures a comfortable and safe environment for building occupants

4. Conclusion

Integrating SA and AI into BMS, leveraging insights from recent research on industrial processes, IoT cloud-edge continuum, and smart cities, can bring considerable improvements in building operations and energy efficiency. By incorporating feedback loops and contextual awareness, the proposed system can adapt to changing conditions and continuously improve performance. This approach not only enhances the functionality of BMS but also supports global sustainability goals by reducing energy consumption and carbon emissions. The framework's focus on real-time monitoring and predictive maintenance aligns with the proposed integration of SA and AI in BMS, enhancing the system's ability to anticipate and address issues proactively. The emphasis on context-aware decision-making supports the integration of SA in BMS, enabling the system to make informed decisions based on environmental and occupancy data . The integration of AI and IoT in BMS aligns with the proposed system architecture, enhancing the system's ability to process data and optimize building operations . The use of machine learning for predictive maintenance supports the integration of AI in BMS, enabling the system to predict and prevent equipment failures, thereby improving reliability and reducing maintenance costs. The concept of adaptive control aligns with the proposed integration of AI in BMS, enhancing the system's ability to respond to changing conditions and optimize building performance. The review provides a comprehensive overview of the potential benefits of integrating AI and IoT in BMS, supporting the proposed system's goals of improving energy efficiency and operational effectiveness. The focus on energy efficiency and sustainability aligns with the proposed integration of SA and AI in BMS, supporting global sustainability goals by optimizing building operations. This comprehensive approach to integrating SA and AI into BMS aims to enhance building operations, improve energy efficiency, and support global sustainability goals. By leveraging insights from recent research and incorporating feedback loops and contextual awareness, the proposed system can adapt to changing conditions and continuously improve performance.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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