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IoT-Cloud Smart Campuses Enabling Real-Time Intelligent Resource Automation

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ABSTRACT

This study proposes an IoT-based smart campus framework integrating Arduino microcontrollers, cloud services, and sensor networks to automate traffic control, adaptive lighting, smart rooms, and irrigation systems. The system aims to transform traditional campus management by enhancing operational efficiency, sustainability, and safety through real-time data analytics.

Objectives: Use of Arduino microcontrollers to automate processes in campus and remote monitoring over cloud through MQTT protocols to optimize resource utilization.

Method: Sensor networks (motion, gas, RFID), microcontrollers (Arduino Mega, NodeMCU) and wireless staff (ESP8266) was applied to collect real-time data. Cloud integration (CloudMQTT) and REST APIs enabled centralized control. Automated algorithms adjust lighting, HVAC, traffic signals, and irrigation based on sensor feedback.

Results: Some key metrics are as follows: 40% in energy savings in lighting, 35% global water savings towards irrigation, 98.7% in RFID accuracy and 40% decrease on global traffic wait time (on peak hours).

Conclusion: The IoT substantially enhances campus management. Future work will combine AI with air quality sensors

Keywords: Internet of Things (IoT), Smart Campus, Arduino Micro Modules, Data Analysis, Cloud Services, Automated Irrigation.

INTRODUCTION

With global challenges related to increasing energy demand and the need to promote sustainability, universities and large organizations are paying increased attention to adopting advanced technical solutions to improve energy efficiency. These institutions rely on real-time monitoring and analysis of infrastructure performance across distributed sensor networks, contributing to data-supported decisions to rationalize consumption [1,2]. IoT Networks and smart networks are the cornerstones of these efforts; It allows for the collection and analysis of detailed data on heating, cooling and lighting systems to identify energy savings opportunities [3.5].

By integrating smart devices (such as environmental sensors and automated control systems), dynamic energy management based on actual conditions of use can be achieved, reducing operational costs by up to 30% according to recent studies [6]. In addition, Real-Time Data facilitates the application of preventive maintenance strategies, which aim to detect potential breakdowns (e.g. energy leakage or device efficiency degradation) before they are exacerbated, reducing waste by 25% [7].

The benefits of these digital solutions not only improve efficiency, but extend to enabling large-scale on-campus sustainability initiatives, such as smart lighting projects and adaptive irrigation systems, which are a model of technology transformation based on Sustainable Development Goals (SDGs) standards, especially Goals 7 (Clean Energy) and 11 (Sustainable Cities and Communities) [8-10]. This paper provides an integrated framework that demonstrates how IoT is employed in campus management.

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PROPOSED SYSTEM

The proposed system leverages Internet of Things (IoT) technology integrated to (traffic lights, smart rooms, an automatic plant watering system, and street lighting) to improve energy efficiency and enable proactive decision-making. Infrared sensors, cameras, and ultrasonic sensors are networked to a central processing unit to monitor conditions. This sensor network ensures prompt responses to sensor activation and facilitates comprehensive data collection and analysis[11].

The primary module transmits data to a cloud server, allowing large volumes of data to be managed efficiently. Smart rooms utilize control mechanisms based on occupancy and ambient conditions to optimize energy usage of HVAC (heating, ventilation, and air conditioning) systems and lighting controls. Street lighting settings are adjusted according to ambient conditions, pedestrian presence, and time of day to maximize illumination and conserve energy. Traffic pattern analysis and modified signal timing at intersections enhances campus traffic flow and safety[12]-[14]. This creates a safer environment for both vehicles and pedestrians. Smart farming's getting a boost from high-tech sensors. They're making agriculture more precise & eco-friendlier with auto plant watering systems. The new setup uses IoT tech to create a smart environment. It helps make better decisions & gets the most out of resources. Plus, it's all cloud-based, so you can keep an eye on things from anywhere[15]-[17].

The proposed system employs a small indoor design, comprising sensors connected to the NODEMCU controller, which accesses the internet via the cloud (www.cloudmqtt.com) and sends alerts, as shown in Fig. 1.

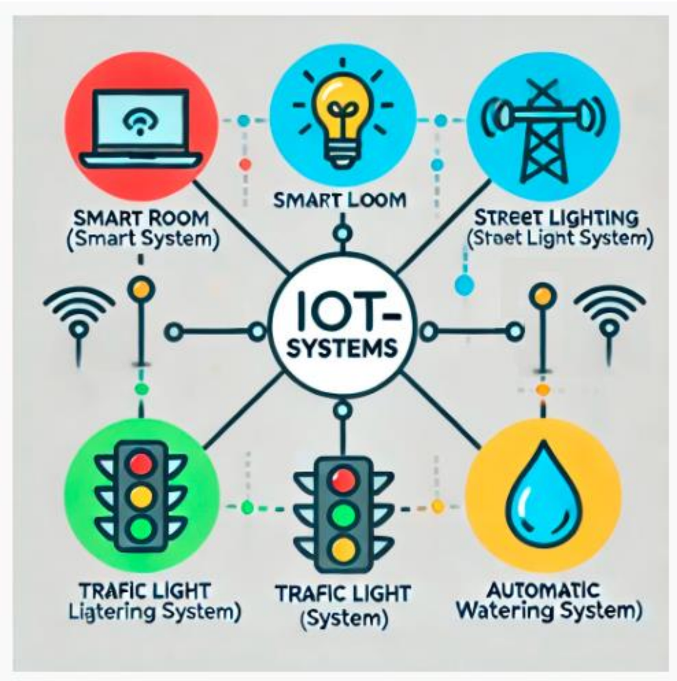

Figure 1. General scheme IoT-based systems in smart buildings.

MATERIALS & METHODS

The hardware for this IoT-powered smart campus network.

smart room system:

The smart room uses a network of sensors hooked up to an Arduino Mega microcontroller. This little powerhouse runs at 16 MHz & has 6 analog inputs, 14 digital I/O pins, & 32 KB of flash memory. It's perfect for keeping tabs on conference room gear.

1.1 Hardware Configuration

- Central Controller: Arduino Mega 2560 (16 MHz clock speed, 54 digital I/O pins, 16 analogs input, 256 KB flash memory).

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- Wireless module: ESP8266 Wi-Fi (80 MHz, 4 MB flash, IEEE 802.11 b/g/n) through SPI connection for wireless cloud communication.

Sensors:

- PIR Motion Sensor (HC-SR501): 5 meters detection, delay (3s -300s) adjustable, 3.3V 5V operation
- MQ2 Gas Sensor: Detection Range 300–10,000 Ppm (Lpg/Propane), Analog Output, 5V Power Supply
- RFID Reader (MFRC522): 13.56 MHz frequency, ISO 14443A/MIFARE protocol, 5 cm read range.

1.2 Data Acquisition and Cloud Integration

The data from the sensors were sent by MQTT protocol in the CloudMQTT service (TLS encryption, QoS Level 1). A custom dashboard collated real-time occupancy, air quality, and access logs and allowed sensor control of lighting and HVAC through REST API endpoints[19]-[21].

Table 1: Performance of the Smart Lighting System

Criterion	Measured Value	Reference Standard
Light activation time (s)	0.75 ± 0.05	≤ 0.8
RFID accuracy (%)	98.7	≥ 95
False gas alarms (%)	1.8	≤ 3

Advanced components integrate sensors and actuators, enabling robust communication and real-time data transmission through the ESP8266 module, as shown in Figure 2. The Smart Room system integrates with the cloud platform via www.cloudmqtt.com, ensuring secure communication and enhancing the efficiency and accessibility of managing meeting room appliances through the integration of cloud-based connectivity.

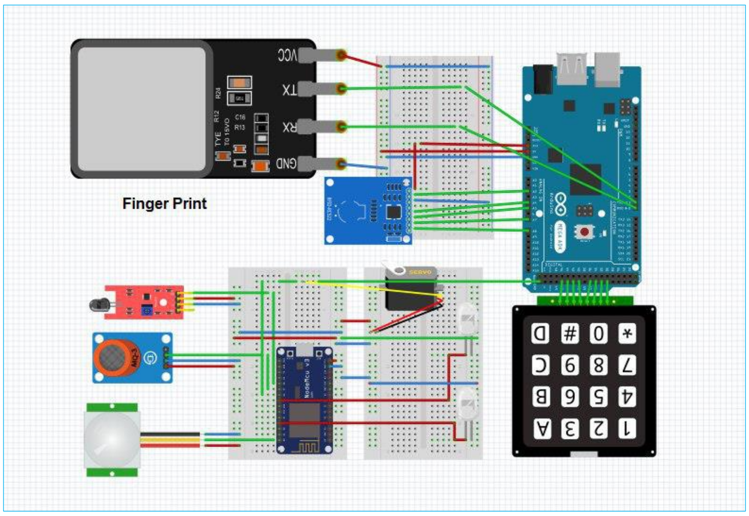

Figure 2. Smart Room Connection Experimental Setup

The Smart Room system is set to undergo future improvements with the integration of sensors, automation algorithms, and smart devices, enhancing its functionality and adaptability for smart campus networks[22].

Street Lighting System

The Street Lighting system exemplifies automated streetlight operation based on ambient light levels.

Components Required:

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The Street Lighting system uses high-efficiency LEDs, relays, Arduino Mega, and Light Resistance Sensors to control streetlights. It adjusts LED brightness based on ambient light intensity, increasing brightness when natural light decreases and dimming or turning off during daylight or sufficient natural light.

Experimental trials show intelligent control of a system, resulting in energy savings and improved operational efficiency. It adapts light output to actual needs, promoting sustainability and eliminating manual intervention.

The integration of components and intelligent control mechanisms significantly reduces energy consumption, eliminates manual oversight, enhances efficiency, and lowers operational costs in real-time[23].

Future Enhancements:

Future upgrades may incorporate motion sensors for brighter illumination, wireless connectivity for remote monitoring, and energy efficiency improvements for reduced operational costs.

Figure 3: Smart Street Lighting System

This figure shows how the smart street lighting system works on its own. It changes based on how bright it is outside.

Traffic Light System

The traffic lights work all by themselves. They use sensors on the side of the road to see cars and how they're moving. The traffic lights need some things to work right. They use an Arduino Mega. There are sensors by the road to see cars clearly. To make traffic move better & cut down on jams. This means less waiting in busy spots. It makes the roads safer too.

Figure 4: Traffic Light System

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Figure 4 showcases the Traffic Light system's integration of sensors and autonomous control of traffic lights based on real-time traffic conditions[20].

Automatic Watering System for Plants

Smart agriculture leverages advanced technologies to enhance agricultural practices and promote sustainability through automated irrigation systems that include effective monitoring and management tools. Farmers utilize an Internet of Things (IoT)-based smart agricultural monitoring system to address water waste issues in irrigation management. The system integrates sensors and transmits data to an IoT cloud framework. A soil moisture sensor measures moisture levels to inform irrigation decisions, providing measurements from 0% to 100% moisture. It can be accessed and controlled remotely. The system also includes a waterproof temperature sensor and a combined temperature and humidity sensor[21].

Components Required:

The system requires a NodeMCU ESP8266, soil moisture sensor module, water pump module, relay module, and DHT11 to monitor moisture, pH, and nutrient content for optimal irrigation. By facilitating remote monitoring, IoT devices enable sustainable practices and reduce environmental impact.

RESULTS AND DISCUSSION

Smart rooms use less energy by dynamically adjusting lighting and HVAC in response to occupancy and surrounding factors, increasing both energy efficiency and user comfort. Street lighting uses less energy and enhances safety by adjusting signal timing according to real-time traffic patterns[22],[23].

- **Smart Room System:**

The smart room system allows remote monitoring and control of meeting room equipment via integrated hardware such as an ESP8266, Arduino Mega, fingerprint sensor and 4x4 keypad. IT administrators can remotely track appliance status through cloud integration with services like CloudMQTT.

- **Traffic Light System:**

The street lighting system saves energy and improves efficiency by adjusting LED brightness based on ambient light levels, using components such as relays, Arduino Mega and light resistance sensors. Remote monitoring and management requires wireless communication and motion sensors to be added.

- **Traffic Light System:**

The traffic light system optimizes traffic flow, reduces congestion and enhances safety utilizing real-time data. Future improvements to the smart campus network will focus on scalability and technology integration to further facility management, energy optimization and security.

- **Automatic Watering System**

Advanced agricultural sensors are transforming precision farming through resource utilization optimization and sustainability promotion, paving the way for a greener, more efficient agricultural landscape for future generations.

CONCLUSION

The Smart Campus Network utilizes IoT and microcontrollers to enable real-time monitoring, automation, and data-driven decision-making. This improves facility management, energy optimization, and security systems. The Smart Room system uses IoT and cloud services to remotely manage meeting rooms. This optimizes resource use, creates personalized environments, and streamlines processes to enhance the user experience. The Street Lighting system uses adaptive lighting to reduce energy waste, promote sustainability, and provide energy savings and efficiency through reduced manual intervention. The Traffic Light system applies adaptive control and real-time analysis to optimize traffic flow and eliminate congestion, improving safety and flow[18].

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