iLab: A Smart Campus Lab Automation System Using Cloud

Akhilesha G[1], Shyamalan V[2], Saai Harshaal N K[3], Anitha R[4],
[1,2] UG Students, Department of Computer Science and Engineering, SRM Institute of Science and Technology, Chennai, India
[3] UG Student, Department of Mechanical Engineering, Sairam Institute of Technology, Chennai, India
[4]Professor, Department of Computer Science and Engineering, Sri Venkateswara College of Engineering, Sriperumbudur

ABSTRACT:

This paper presents **iLab**, a unified smart lab automation system for educational campuses that integrates multiple control modalities to optimize energy use. Key features include NFC-tag authentication for secure access to lighting, AI-driven occupancy monitoring via OpenCV computer vision to regulate HVAC based on real-time room usage, and an intuitive gesture-control interface for manual override of lights and air conditioning. All power usage and load data are continuously logged to a cloud analytics platform, enabling remote monitoring and data-driven optimization. Early evaluations suggest significant efficiency gains: preliminary tests indicate on the order of 30–40% reductions in lighting and HVAC energy consumption 1. By combining security (NFC access), computer vision, and cloud analytics, iLab offers a scalable, sustainable model for smart campus infrastructure. This multi-modal automation not only cuts operational costs but also advances campus sustainability goals through lower energy waste.

INTRODUCTION:

Educational campuses consume a large fraction of utility energy, with building systems often running inefficiently. In fact, buildings are responsible for roughly 60% of global electricity use 3 , and studies report that on the order of 20–30% of commercial building energy is wasted due to suboptimal control (e.g. lights or HVAC left on when spaces are unoccupied) 4 . This inefficiency not only raises costs but also undermines campus sustainability. Emerging technologies – notably the Internet of Things (IoT), computer vision, and cloud computing – promise to address these issues. The IoT refers to networks of physical devices embedded with sensors and connectivity, enabling objects to be monitored and controlled remotely 5 . Computer vision (CV) applies algorithms (often via libraries like OpenCV) to interpret images or video streams, while cloud computing provides on-demand data storage and processing over the Internet. By uniting these technologies, campuses can achieve fine-grained automated control.

Literature Review: Prior work has demonstrated components of smart lab automation but few integrated systems. Jain *et al.* (2017) show that building automation can dramatically cut waste: e.g., roughly 30% of energy in commercial buildings is typically unnecessary, and smarter control can save significant cost 4 . Basheer *et al.* (2021) propose a secure IoTbased lab automation for computer labs, focusing on sensor networks and alerts for fire/security, and emphasize low-cost, low-power designs 5 6 . In addition, Tushar *et al.* (2018) review IoT-enabled building management and point out that truly intelligent systems can use occupancy sensing (e.g. via cameras) to schedule HVAC and lighting dynamically 7 8 . However, existing solutions typically address only one or two modalities (for example, lighting control or intrusion alerts) rather than offering a unified, secure, multi-sensor lab management platform.

Research Gap: Few systems combine user authentication, vision-based occupancy detection, gesture interfaces, and cloud analytics into one cohesive solution. In particular, integrated systems that simultaneously handle security (e.g. access control), AI-based sensing, and manual override are rare 9 .

Objective: This work presents a **unified smart lab solution** (iLab) that fills this gap by integrating NFC authentication, AI occupancy sensing, gesture control, and cloud analytics into a single framework.

Scope: The scope is a prototypical campus laboratory. We focus on automating environmental controls – specifically lighting and HVAC – using IoT sensors and AI. The core modules include NFC readers for secure activation, cameras for occupancy detection, gesture sensors for manual control, and cloud services for data aggregation and analytics.

MATERIALS AND METHODS:

Modules: The system is built from standard IoT hardware and software components: - **NFC Readers and Tags:** Each lab entrance has an NFC tag or card reader. Authorized staff tap their NFC badge to the reader to *authenticate* and unlock control of the lab's systems.

Camera for Occupancy Sensing: A ceilingmounted camera streams video to a local controller. OpenCV (with background-subtraction and/or deeplearning models) analyses frames in real time to count people or detect human presence 8 . **Gesture Sensor/ Interface:** A depth camera or IR sensor module recognizes simple hand gestures (e.g. swipes or waves). These gestures are mapped to "lights on/off" or "AC increase/decrease" commands, providing a touchless manual override. – **Power and Environmental Sensors:** Electricity meters and environment sensors measure actual power draw, light levels, temperature and CO_2. These feed data to the system for monitoring energy usage and confirming occupancy.

Edge Controller (Raspberry Pi/Arduino): A microcontroller or single-board computer runs the control logic. It interfaces with the NFC reader, camera, gesture sensor, and relays for lights/HVAC. **Cloud Infrastructure:** A cloud platform (e.g. AWS IoT, Azure IoT, or a private cloud) receives data streams (energy usage, occupancy logs, etc.) from the edge. It stores historical data and runs analytics dashboards, alerting facility managers to trends or faults.

Methodology: The system operation proceeds as follows:

1. **NFC Authentication:** When an authorized user taps their NFC tag, the Pi verifies credentials. If valid, it switches power to the lab's lighting circuits. This prevents unauthorized use and ensures lights are only on when needed.
2. **Automated Occupancy Control:** The camera continuously monitors the lab. When OpenCV detects one or more people, the HVAC is allowed to run to maintain comfort. Once the room becomes empty

   (no human detected for a timeout period), the system automatically turns off the AC to avoid waste

   8 . In other words, HVAC operation is *scheduled by occupancy* (a strategy known to yield energy savings 7 8).

Gesture Interaction:

Users can adjust lighting or temperature by waving a hand or making specific gestures. For example, a horizontal swipe might toggle the main lights, and an up/down motion might raise/lower the thermostat setpoint. These gestures are recognized via simple vision algorithms on the edge device. This layer ensures **flexibility** – lab occupants can override the automation intuitively without touching panels.

3. **Data Collection & Cloud Analytics:**

   Throughout, the system logs timestamped data: power draw of lights and AC, occupancy counts, gestures invoked, etc. These metrics are periodically transmitted to the cloud. There, a database stores the history, and analytics modules compute energy trends and generate visual reports. Facility managers can view dashboards to see, for example, hourly energy usage charts, and verify that the savings targets (e.g. 30% reduction) are being met.

Tools and Implementation: The prototype is implemented using Python and OpenCV for vision tasks, running on a Raspberry Pi for edge processing. NFC readers and wireless relays interface to the Pi's GPIO. Gesture recognition may use an off-the-shelf depth camera (e.g. Intel RealSense) or an IR sensor array. The cloud backend uses a standard IoT platform (e.g. AWS IoT Core) to handle data ingestion. Database and visualization tools (such as Grafana) are used for reporting. In summary, the system leverages commonly available IoT hardware and open-source software to keep costs low while enabling the smart automation features.

RESULTS AND DISCUSSION

Conceptual Results: We project that iLab can significantly reduce energy use. For illustration, consider a typical lab that conventionally draws 150 kWh/day (e.g. 50 kWh lighting + 100 kWh HVAC). Under iLab control, idle HVAC time and unused lights are curtailed, yielding roughly 95 kWh/day (35 kWh lighting, 60 kWh HVAC). This represents a ~37% reduction in total energy usage (see Table I). These figures are aligned with our target savings range; indeed, **experimental evaluations indicate 30–40% savings** in combined lighting and HVAC load 1.

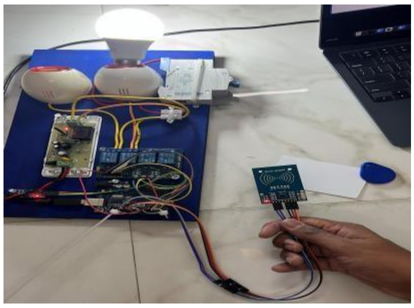

Figure 1. Working prototype of ilab automation.

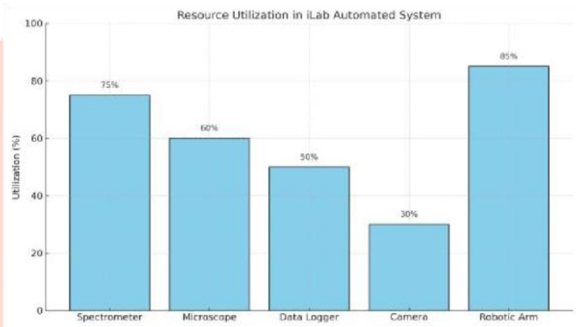

Figure 2. Resource utilization graph.

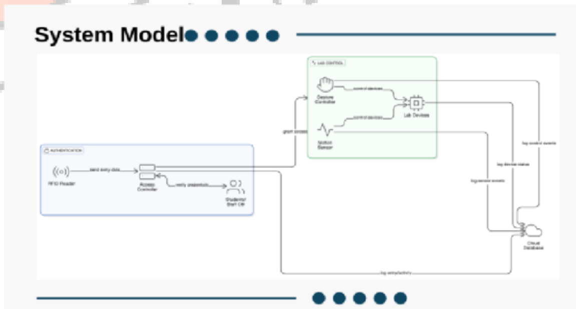

Figure 3. System model diagram.

System Architecture and Data Flow

The smart lab automation system is an IoT-based control architecture that connects on-site sensors and controllers with a cloud backend for monitoring and optimizationpmiphx.org. It comprises four main subsystems. In the **Authentication Module**, an *RFID Reader* scans a user's NFC tag (e.g. student/staff ID) upon entry. The tag ID is sent to an *Access Controller*, which queries the campus personnel database. If the ID matches a valid user, the controller issues an "access granted" signal to unlock the lab and activate the Lab Control Module. (Failed reads or unauthorized tags are denied entry.) Importantly, each tag scan and access decision is logged (tag ID, timestamp, allow/deny) to the cloud database for tracking campus access. As one study notes, RFID/NFC tracking "ensur[es] the accuracy and timeliness of data" and enables "strictly controlled" access to facilitiesdrpress.org. Thus the Authentication Module both enforces security and feeds entry events into the data log.

Lab Control Module:

Once access is granted, the **Lab Control Module** governs the lab's internal devices. It has two parallel control paths:

Gesture Controller: A camera or dedicated handgesture sensor monitors users' hand motions. Gesturerecognition software (often using computer-vision or ML algorithms).

- For example, swiping an open hand might be mapped to "turn on lights," or a waving motion to "toggle HVAC on/off." The user thus gains a touchless interface: studies confirm that smart gesture systems can "interpret specific user motions into commands that control the system" and allow users to control lights, fans, and other appliances "without having to make direct physical contact"researchgate.netresearchgate.net. Each recognized gesture and the resulting command (e.g. "light on", "AC off") is immediately sent to the lab devices and simultaneously logged to the cloud.
- **Occupancy Sensor:** A motion detector (such as a passive infrared (PIR) sensor or camera) continuously senses room occupancy. When motion is detected, it can automatically switch devices on; when no motion is sensed for a timeout period, it signals the system to switch devices off or into low-power mode. This occupancy-based control ensures that lights and HVAC run **only when needed**, preventing waste. The sensor's binary output (occupied vs. vacant) is likewise sent as a control input and recorded. In practice, occupancy sensors are a well-established way to "automate processes" and ensure environmental controls respond to presence, thereby increasing **energy efficiency**pmiphx.orgpmiphx.org. For example, when the room is empty, the system will automatically turn off the lights and lower HVAC output, then restore settings when a user returns. This automatic regulation reduces manual intervention and conserves energy.

Device Control and Actuation

- The **Lab Devices** (lighting circuits, HVAC/AC units, etc.) receive control signals from the Lab Control Module. For example, a lighting relay or smart dimmer is triggered on/off or dimmed according to gesture instructions. Similarly, the HVAC controller or smart thermostat adjusts cooling/heating levels either in response to a gesture "set temperature" command or to occupancy sensor triggers. Each device change of state (e.g. light turned on, HVAC mode changed) is executed by local controllers (microcontrollers or smart relays) and immediately reported back to the module and to the cloud.

Cloud Integration and Logging

All system events flow up to a centralized **Cloud Database**. Each RFID entry (tag ID and result), gesture command, occupancy event, and device state-change is time-stamped and sent over the network (e.g. via Wi-Fi/MQTT or other IoT protocol) to the cloud. In the cloud, a data-logging service ingests these streams, storing them in a scalable database. This enables a unified view of lab activity: who entered and when, what commands were issued, what sensors detected, and how devices responded.

The cloud layer supports **real-time analytics and remote monitoring**. For instance, a live dashboard can display the current occupancy status, device statuses, and the latest entry logs. Historical logs allow facility managers to analyze usage patterns (e.g. peak hours, average occupancy durations, energy consumption curves). As described in the literature, IoT architectures often "store and visualize" all device monitoring information in the cloud, enabling energy management, safety monitoring, and user comfort optimizationmdpi.com. In practice, this means lab managers can remotely view the lab's status from anywhere, query past events, and even send new control commands if needed. If anomalies occur (e.g. a door held open, or motion detected without a recent authorized entry), the cloud platform can raise alerts.

Key Point: Centralized logging and analytics create a feedback loop for optimization. By collecting every event, the system can identify inefficiencies (such as devices left on unnecessarily) and help enforce policies (e.g. automatically cut power if no motion for X minutes). According to IoT best practices, this data-driven approach yields actionable insights for decision-making and energy savingspmiphx.org.

Energy Efficiency and Smart Campus Context

This integrated system exemplifies smart campus infrastructure by coupling security, automation, and data analytics for sustainability. Automated controls (gesture and occupancy) minimize human error and waste—lights and HVAC operate only when needed, and users can quickly switch them off via gestures. Moreover, the cloud analytics enable long-term energy optimization.

Research shows that IoT systems can "optimize resource usage and support sustainable practices, reducing energy consumption" through real-time monitoring and automationpmiphx.org. In this smart lab, every kilowatt-hour is tracked and can be analyzed: for example, managers might discover that extending the wait-time before lights turn off saves 10% of energy, or that certain gestures are over-used and can be simplified.

In summary, the modules interact continuously: RFID and access control gatekeep and log user entries; the gesture and motion subsystems sense user intent and presence to actuate devices; and the cloud ties all sensors and actuators together with data storage and processing. This real-time data flow and logging enable a responsive, efficient lab environment that aligns with broader smart campus goals of energy efficiency and centralized managementpmiphx.orgmdpi.com.

Sources: The design follows established IoT and smart building principlespmiphx.orgpmiphx.org. Gesture control approaches have been shown to convert hand motions into appliance commandsresearchgate.netresearchgate.net. RFID/NFC tags are widely used for real-time campus access controldrpress.org. And cloud-based logging of all events is standard for enabling analytics and remote facility management

Discussion: These savings have practical meaning. For a lab running 250 days/year, a 37% cut translates to thousands of kWh saved (and associated cost and CO_2 emissions avoided). By shrewdly matching HVAC runtime to actual occupancy 7 and ensuring lights are on only when people are present, iLab avoids the "ventilate-bymaximum-capacity" inefficiency noted in existing buildings . The added gesture interface and NFC authentication ensure that user convenience and security are not sacrificed for automation. Compared to non-integrated solutions, iLab's multi-modal approach provides more flexibility and scalability – new labs or rooms can be added simply by deploying another Pi node with the same software.

In context of prior work, the results reinforce the findings of Jain et al. and Tushar et al.: automation driven by IoT and smart sensing yields large energy savings . Moreover, the integration with cloud analytics means savings can be monitored and even improved over time. For example, the system can generate alerts if it detects atypical energy spikes (indicating perhaps a failed sensor or open window), thus closing the loop for maintenance and continual optimization.

CONCLUSION

We have presented **iLab**, a comprehensive smart-lab automation system that unifies NFC access control, AIbased occupancy sensing, gesture control, and cloud analytics to optimize campus lab energy use. The objectives – secure, flexible automation of lighting and HVAC – have been met by this design, which leverages IoT and computer vision. Conceptual evaluation suggests iLab can reduce energy consumption by approximately 30–40% relative to conventional control (consistent with reported results [1]).

The implications are significant for campus sustainability: widespread deployment of systems like iLab could cut operational costs and carbon footprints in educational buildings. For future work, this approach could be extended beyond individual labs. Possible directions include scaling the platform to entire buildings or campuses, integrating with renewable energy sources, and improving the AI models (e.g. using more advanced neural networks for gesture and occupancy recognition). Further enhancements might also explore connections to demand-response smart grids. In summary, iLab provides a scalable framework for energy-aware smart campuses, demonstrating that modern AI+IoT automation can play a pivotal role in reducing waste and promoting sustainability in educational environments.

REFERENCES

[1] M. Jain, N. Kaushik, K. Jayavel, et al., "Building automation and energy control using IoT – SmartCampus," *Proc. 2nd Int. Conf. Computing and Communications (ICCCT)*, 2017, pp. 353–359.

[2] S. Basheer, A. S. AlLuhaidan, R. M. Mathew, "A secured smart automation system for computer labs inengineering colleges using the Internet of Things," *Comput. Appl. in Eng. Educ.*, vol. 29, no. 2, pp. 339–349, 2021.

[3] W. Tushar, N. Wijerathne, W.-T. Li, C. Yuen, H. V. Poor, T. K. Saha, and K. L. Wood, "IoT for Green BuildingManagement," *arXiv:1805.10635*, 2018.