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PROPOSED SMART UNIVERSITY MODEL: THE INTEGRATION OF IOT AND FUZZY LOGIC IN SMART CLASSROOM FOR OPTIMIZING THERMAL COMFORT

ZAHRA OUGHANNOU[1,*], IBTISSAME KANDROUCH[1], NOUR EL HOUDA CHAOUI[1], HABIBA CHAOUI[1], SALMANE BOUREKKADI[1, 2]

[1]Ibn Tofail University, Kenitra, Morocco

[2]EFSI Sarthe France

*Correspondence: oughannou.zahra@gmail.com

ABSTRACT

In the era of rapid urbanization, the emergence of "smart universities" provides a promising solution for the sustainable development of education. This article explores the transformative potential of integrating the Internet of Things (IoT) and fuzzy logic control in the education sector, with a specific focus on optimizing thermal comfort in classrooms. We begin by analyzing the fundamental principles of smart universities, emphasizing the central role of Information and Communication Technologies (ICT) in enhancing educational experiences. Drawing from various studies, we delve into the application of IoT in diverse educational contexts, emphasizing the creation of interactive learning environments and the rise of smart education. We present our proposed smart classroom architecture, taking into account the contextual considerations. Our Smart University model focuses on a crucial challenge: real-time analysis, aiming to propose an efficient architecture while considering the nature of technologies used within the Smart University. Our model is based on Fog Computing and Edge Computing to meet storage requirements, reduce communication load between Fog Nodes and sensors, and enable real-time analysis. Furthermore, we undertake an in-depth exploration of MQTT architecture, highlighting its significance in the client-server model. The article emphasizes the achievable improvement in thermal comfort through the fusion of IoT and fuzzy logic control, presenting a revolutionary approach to the management and optimization of classrooms. Through this comprehensive study, we envision a future where technology seamlessly integrates into the university landscape, offering sustainable and intelligent solutions to address contemporary challenges.

Keywords: *Smart University, IoT, Cloud Computing, Fog Computing, Wireless Communication, Fuzzy Logic, MQTT.*

1. INTRODUCTION

Amid rapid global urbanization, sustainable development has become a critical challenge, particularly in the context of city development. The evolving concept of "Smart Cities" reflects a modernized approach to urban development, emphasizing the enhancement of urban life for current and future generations with a citizen-centric focus. This approach heavily relies on the integration of Information and Communication Technology (ICT), particularly the Internet of Things (IoT), across various sectors crucial to citizen well-being, such as transportation, healthcare, energy, and environmental management [1,2]. This integration, characterized by the deployment of sensors and actuators, robust Machine-to-Machine (M2M) communication infrastructures, and advanced data processing techniques, is central to the delivery of enriched services and applications in Smart Cities as depicted in Figure 1.

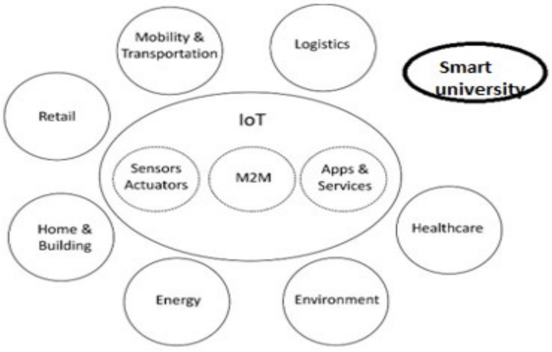


Figure 1: Overview Of The Core Technologies And Main Application Areas Covered Under The Smart City Paradigm

Alongside the development of Smart Cities, the concept of "Smart University" has emerged within the educational sector. Smart Universities represent a comprehensive integration of technology and academia, aiming to create sustainable, efficient, personalized learning ecosystems. These institutions are at the forefront of merging digital innovation with educational practices, aligning with the broader goals of sustainable smart education [3].

Recent research in innovative education has been instrumental in developing smart campuses and intelligent educational systems. For instance, in [4], the authors highlight the significance of IoT tools in meeting the core needs of education, such as facilitating interactions among students, parents, and teaching staff via intelligent platforms. Similarly, [5] discusses an open-source IoT system designed to raise awareness of energy consumption behaviours in educational settings, enhancing environmental Sustainability.

However, despite these advancements, there is a notable gap in the application of IoT for optimizing the physical learning environment, particularly regarding thermal comfort in classrooms. Studies like [6] and [7] focus on monitoring device usage and energy consumption, or on enhancing conventional education methodologies through IoT and cloud infrastructure, but do not address the specific challenge of creating a comfortable learning environment.

In [8], a comprehensive examination of intelligent cities, smart microgrids, and city ranking systems is presented, focusing on identifying key performance indicators for university campuses. This study highlights the significance of energy consumption and carbon footprint management in the context of a university campus. It also emphasizes the need for a campus management mechanism that monitors and utilizes microgrid systems. However, the study points out a critical gap: the lack of comprehensive data analysis, which restricts the ability of universities to make informed, data-driven decisions.

Similarly, [9] introduces a framework for monitoring and managing IoT systems, utilizing AllJoyn for device interconnection, MongoDB for data storage, and Storm for real-time analytics. The empirical evaluation within a smart home context provides insights into the impact of management applications on system performance, indicating that monitoring and service latencies are significantly affected by these applications.

Further, [10] discusses identifying fundamental criteria for developing smart campuses and proposing a strategic framework encompassing various components. This framework underscores the central role of IoT and Cloud Computing as critical pillars of infrastructure, covering a range of applications, including smart cards, smart classrooms, and energy management systems.

A recent literature review reveals significant progress in developing innovative campus technologies. Studies such as [8], [9], and [10] highlight the importance of IoT and cloud-based frameworks in enhancing various campus operations, from energy management to data analytics. However, these studies predominantly focus on broader campus infrastructure and management, leaving room for improvement in classroom environment optimization.

While current research in smart campus technologies has made significant strides in areas like energy management and infrastructure optimization, the specific application of these technologies for enhancing the classroom environment, especially thermal comfort, has yet to be extensively explored. This paper identifies this as a critical research gap and proposes a solution that combines the real-time monitoring capabilities of IoT with the adaptive and precise control offered by fuzzy logic systems.

The proposed methodology involves a systematic approach, starting with defining the concepts of Smart Campus and Smart University. It then explores essential communication frameworks, focusing on the MQTT architecture, which is pivotal for the efficient functioning of IoT networks in a client-server model. The paper will delve into the details of designing and implementing an IoT and fuzzy logic-based system tailored explicitly for managing classroom thermal comfort.

2. DEFINITIONS OF SMART CAMPUS AND SMART UNIVERSITY

The smart city concept emerged in the 1990s and represents the convergence of technology and modern urban planning. This concept has matured over the years and now stands as a dynamic research direction, yielding an increasing number of publications. Medium-sized university campuses are comparable to smart cities, with communities of moderate to large sizes encompassing a wide range of interests. In Spain, municipalities with populations exceeding 10,000 are considered cities. Presently, Spain hosts 753 municipalities with a collective population of 37.74 million, each averaging around 50,000 inhabitants. Innovative university, a subset of the smart city concept, derives from the notion of an innovative campus. It involves the integration of cloud computing and IoT (Internet of Things) technologies, creating intelligent campuses that enhance teaching, management, and research within universities [11].

Brilliant universities encompass various aspects of campus services, including environmental, financial, and social dimensions. However, our research focuses on the educational aspect within the framework of Smart Universities. The goal of making universities "smart" is to offer an intelligent learning system, which refers to the increasing use of digital tools that enable progressive teaching, catering to the digitally-connected generation of learners who use technology to learn, stay informed, and engage with the world. This has led to the adoption of various intelligent solutions in university environments to enhance the quality of life and the performance of both teachers and students [11].

It's essential to begin by delineating the term "smart campus." Historically, this phrase has been linked to digital online platforms managing university content [12,13] or methods designed to amplify the academic prowess of university students [14,15]. In the context of this article, however, "smart campus" explicitly denotes the hardware and software infrastructure designed to offer sophisticated, context-aware services and applications to university students and staff. Concurrently, the term "smart university" alludes to the technological framework that crafts tools addressing the three pivotal dimensions of a university's mission:

- ✓ Enhancing the teaching, learning, and assessment processes is integral to higher education.
- ✓ Promoting a culture of research and innovation.
- ✓ Catalyzing knowledge transfer within the community, fostering a collective vision among diverse university stakeholders — ranging from educators and students to administration, non-profit entities, research bodies, the general public, industries, and government entities.

This nuanced understanding sets smart campuses and universities apart from broader concepts like smart cities. However, parallels do exist between brilliant campuses/universities and smart cities, especially concerning their organizational structure, which gravitates around six core areas [16]:

Innovative Governance: Empowers university personnel and students to actively participate in various decision-making processes, whether institution-wide or campus-specific.

Smart People: Concentrates on the active involvement of university members in pedagogical activities and their participation in significant events.

Smart Mobility: Within a campus setting, it addresses the nuances of transportation systems, advocating for solutions that are eco-friendly, efficient, secure, and infused with intelligent services.

Bright Environment: Proposes innovative solutions for real-time monitoring, protection, and intervention concerning environmental factors. This might include monitoring waste, gauging water usage, or assessing air quality. Additionally, it encompasses systems that oversee energy consumption, production, and distribution across the campus.

Smart Living: Oversees various factors pivotal to daily campus life, from health and safety to behavioural patterns. For instance, intelligent living services might [17,18]:

- ✓ Gauge classroom occupancy and assess student attendance.
- ✓ Oversee access to classroom or laboratory equipment.
- ✓ Deliver interactive teaching services and context-sensitive applications.
- ✓ To encapsulate the concept, Figure 2 provides a visual representation of the primary sectors and technologies integral to the establishment of an intelligent campus/university. The core circle delineates the six aforementioned innovative domains. Encircling this is another layer, pinpointing pivotal technologies that underpin solutions for these domains, encompassing the Internet of Things (IoT), Augmented Reality (AR), Cyber-Physical Systems (CPSs), and Unmanned Aerial Vehicles (UAVs). Intriguingly, several of these technological tools resonate with the tenets of Industry 4.0 [19], hinting at their adaptability in both commercial and industrial contexts beyond educational campuses [20,21].
- ✓ It's also worth noting that overarching domains, such as cybersecurity, span multiple technologies, serving as a foundational layer to mitigate potential challenges [22]. Extending further outward, the outermost circle in Figure 1 sheds light on specific innovative sectors that intricately weave into the daily operations of an intelligent campus/university. For instance, easily integrable smart objects [23] find application across numerous campus activities, while specific environmental sensors play a pivotal role in shaping intelligent buildings [24]. Additionally, there are niche sectors like smart agriculture, tailored for campuses

boasting cultivation zones, necessitating autonomous decision-making systems [25].

Figure 2: Main fields and technologies of an innovative campus.

3. COMMUNICATION FRAMEWORKS FOR INTELLIGENT CAMPUSES/UNIVERSITIES

While numerous scholars have introduced various architectural frameworks for smart campuses, a predominant model emerges: the Service-Oriented Architecture (SOA) [26,27]. This framework principally intertwines two paradigms: the Internet of Things (IoT) and cloud computing [28]. Furthermore, integrating Big Data amplifies these architectures' capabilities, especially in data processing and analysis.

An example is in [29], which details a cloud-based innovative campus framework. Remarkably, this platform was constructed in a mere three months, leveraging Commercial Off-The-Shelf (COTS) hardware combined with Microsoft Azure's cloud services. IoT's utility in streamlining architectural deployments is evident, particularly in applications spanning from learning modules and access control to resource water management [30,31].

Innovatively, some scholars have explored alternative paradigms. The work in [32], for instance, introduces an architecture centred on opportunistic communications, enabling data sharing in infrastructure-less scenarios. This architecture's distinctiveness lies in its 'Floating Content node' concept, a device generating data shareable amongst proximate users. Variants of this model have been explored with enhancements in areas such as security [33].

Recent advancements have directed attention towards edge computing paradigms, like mobile edge computing and fog computing, which have proven effective in other innovative domains [34]. The allure of edge computing stems from its capacity to redistribute processing tasks, shifting them from the Cloud to proximate 'edge devices' linked to IoT nodes. This redistribution minimizes cloud communication, reduces latency, and facilitates location-sensitive services [35,36].

For instance, [37] harnesses edge computing to augment its brilliant campus architecture, emphasizing content caching and bandwidth allocation. Similarly, [38] showcases a novel approach, embedding edge computing within street lights to provision smart campus utilities. The WiCloud platform, as described in [39], exemplifies another facet, utilizing mobile edge computing to offer server access via mobile base stations or wireless nodes. Notably, the system in [40] adopts fog computing nodes, enhancing the overall user experience on smart campuses. Amidst the challenges posed by IoT systems, such as scalability, device heterogeneity, and latency issues in specific Cloud environments, a transformative paradigm named "Fog Computing" has been introduced [41]. This paradigm decentralizes applications, management, and data analytics directly within the network. A global architecture [41] emerges within this context, weaving together devices, sensors, and data interactions across a distributed network that spans Cloud and Fog layers. The crux of the challenge is designing a system that balances data processing, latency reduction, and scalability, all while leveraging the capabilities of Fog Computing.

Situated closer to edge devices, the Fog layer plays a pivotal role, enabling real-time data analysis and local decision-making and lightening the load on central cloud infrastructures. This decentralization approach, shifting towards Fog Computing, promises enhanced efficiency and agility in IoT ecosystems. Furthermore, Fog Computing introduces "edge intelligence", endowing devices with autonomous decision-making based on real-time insights. However, transitioning to this architecture demands careful consideration of data distribution, security, and resource allocation.

In essence, the integration of IoT with Fog Computing offers a promising avenue to overcome the limitations of conventional Cloud-based methods, signalling a shift towards a more distributed and adaptable ecosystem. This merger holds the potential for refining Smart University frameworks and accentuates the pressing need for continued research in this evolving domain. To clarify the previously mentioned architectures, figures 3 and 4 illustrate their evolution. In those figures, at the top, the traditional cloud-based architecture is depicted, which is composed of three main layers:

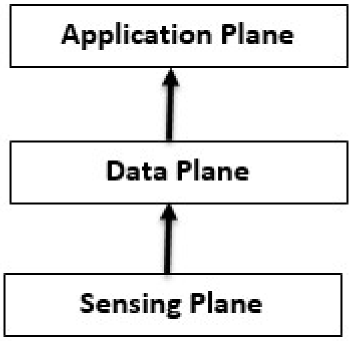


Figure 3: A high-level representation of the Smart University application architecture, composed of 3 layers: application, data, and detection

Figures should be labelled with "Figure" and tables with "Table" and should be numbered sequentially, for example, Figure 1, Figure 2 and so on (refer to Table 1 and Figure 1).

As illustrated in Figure 4, the intricate structure of a Smart University is composed of three collaborative yet interdependent layers: the detection, data, and application planes. These layers offer diverse functionalities essential for the optimal management of a Smart University. Within the realm of Smart University, all institutions are interconnected, leading to a surge in data. This vast amount of data requires real-time storage and analysis to make timely decisions. Such analysis plays a pivotal role in enhancing the learning experience for all students, especially for those with disabilities. By leveraging artificial intelligence algorithms, it's possible to analyze student movements and gestures, offering a tailored educational approach. Furthermore, real-time monitoring and maintenance of devices become feasible. To cater to these demands, we introduce our proposed architecture, as depicted in Figure 4:

Detection Layer: This layer is responsible for data acquisition, typically through either dedicated or non-dedicated sensing mechanisms.

N-Devices: The active or passive objects within the Smart University generate valuable data. Grouped based on their Fog Nodes, these devices efficiently transmit captured data to Fog Computing using various wireless technologies.

Smart RFID Sensors: These devices detect, receive, and store data. Employed in numerous smart environments, they can monitor environmental parameters, track real-time movements, and enable wireless communication.

Communication Technologies: IoT networks play a pivotal role, evolving from wireless body area networks (WBAN) to wide-area networks and wireless tech like RFID, which is particularly beneficial for cost-effective, short-range communication in Smart University environments.

Data Layer: This houses lightweight, real-time data processing at the edge (Fog Computing) and massive datasets sent to the Cloud for deeper analysis.

Fog Nodes: Physical or virtual components, like gateways or servers, that manage data and bridge the gap between end devices and centralized computing services. They enable real-time processing, which is essential for monitoring and enhancing learning experiences.

EDGE Nodes: These peripheral devices are for in-depth data analysis, leveraging advanced algorithms like Deep Learning and Machine Learning, ensuring reduced data processing latency.

Wired Network: This employs fibre-optic technology for rapid data transmission to the Cloud, ensuring efficient data flow.

Application Layer: The Cloud, offering a multi-layered network topology, is pivotal. Adopting Platform-as-a-Service (PaaS) simplifies communication and coordinates object access across various applications. Algorithms, including machine learning and deep learning, are then applied to raw data, extracting valuable insights for primary Smart University applications such as voice recognition, facial recognition, and more.

The integrated interplay of these layers in the Smart University framework ensures a streamlined, efficient, and intelligent educational environment, catering mainly to diverse student needs, including those with disabilities [41].

4. OUR PROPOSED SMART CLASSROOM ARCHITECTURE

In this study, we present a comprehensive architecture composed of three distinct components: a universal smart classroom blueprint, a technology amalgamation framework, and foundational support mechanisms tailored for the seamless functioning of intelligent classrooms. The smart classroom blueprint draws inspiration from our research and insights from our project initiative. The technology amalgamation framework offers a structured approach to unifying varied technologies in a smart classroom, ensuring streamlined access to all embedded devices. Meanwhile, the support mechanisms, from a technological standpoint, encapsulate essential principles and guidelines vital for the effective operation of the proposed model.

4.1 Smart Classroom Prototype

Within this segment, we put forth an innovative prototype for a context-aware smart classroom. This prototype has been developed through an evolutionary progression, beginning with technology-enhanced classrooms, transitioning to smart classrooms, and ultimately arriving at context-aware smart classrooms. The ensuing subsections delve into the distinct features and functionalities of each iteration. Much of this prototype's design draws inspiration from our proposal project. For illustrative purposes, we incorporate visuals from our proposal project, highlighting pertinent components with white annotations.

Our design emphasizes the integration of sophisticated software utilities, including facial and voice recognition, noise filtration, and gesture interpretation capabilities. Additionally, we've expanded our architecture to encompass student-specific voice recognition and offer prompt, high-fidelity translations across English and other languages.

Furthermore, our design equips educators with advanced tools, ranging from facial and voice recognition to intuitive pointing devices and interactive boards, streamlining content presentation and engagement. At its core, our model seeks to immerse learners, whether physically present in smart classrooms or labs or joining remotely [42].

Achieving this holistic vision demands a multifaceted integration of both hardware and software components, ensuring a fluid operation for our Smart University framework. Here, we explore the foundational technologies underpinning this ambitious endeavour.

4.1.1 Hardware

Our infrastructure is fortified with various cameras capturing classroom dynamics, interactions, and student expressions. Overhead projectors, occasionally offering 3D capabilities, and expansive display screens anchor the visual aspect of the classroom. Dedicated displays cater to remote student participants. Communication is facilitated via devices such as smartphones, PDAs, and laptops, fostering a dynamic exchange of information between educators and learners. A comprehensive suite of sensors, spanning from location and temperature sensors to facial recognition, underlies our setup [42].

Additional hardware elements encompass interactive whiteboards, tablets, 3D printers, digital textbooks, identification systems, ambient sensors, modern lighting solutions, real-time attendance trackers, secure access mechanisms, and ergonomic seating options. The entirety of this advanced setup can be managed via educator devices. Such classrooms are IoT-enabled, fostering real-time data capture in intelligent environments, often in sync with cloud platforms [43].

4.1.2 Software

The software backbone of our model includes:

1. Access to a comprehensive Learning Management System (LMS) or a university-wide equivalent.
2. Cutting-edge multimedia software for a dynamic content experience.
3. Assistive tools tailored for special needs students, such as those with visual impairments.
4. Software for wide-angle camera capturing.
5. Advanced recognition software modules.
6. Stability software for motion and hand gestures.
7. Ambient noise reduction utilities [42].

Together, these software systems sculpt the digital foundation of our Smart University blueprint, ensuring a rich, adaptive, and inclusive academic environment for all participants.

5. THE SMART CLASSROOM TECHNOLOGY INTEGRATION MODEL

The concept of a smart classroom is built upon the integration of various sensors and devices. To ensure accurate data collection and effective control in a smart classroom, engineers must devise diverse ways to interact with these devices. Turning a simple command into reality often involves a series of complex actions.

The transformation of a regular school building into an Internet of Things (IoT) integrated entity is vital. Traditional building components, often devoid of direct connectivity, can be upgraded with sensors, energy-efficient processors, and wireless communication features. These enhanced components can then effortlessly connect to smartphones or Internet gateway devices in proximity.

The prototype of this initiative is rooted in the use of a Raspberry Pi, coupled with a range of sensors, Bluetooth and WiFi modules, a fog gateway server, and a cloud platform that facilitates online data storage and analysis. This robust infrastructure paves the way for the remote operation of building devices from any location globally. The envisioned smart-university encompasses not just smart classrooms but extends to smart offices, entrances, and security systems. These features provide automation and are imbued with the intelligence to react based on environmental cues. Although these components have the autonomy to function with their inbuilt intelligence, the primary objective remains to facilitate centralized control through smartphones or computers. This feature ensures efficient monitoring and management of the smart classroom. An added advantage is the system's capability to dispatch email alerts in case of device issues or relay system updates via phone calls.

The goal is to create an automated Smart Classroom that minimizes energy wastage, reduces human monitoring and control efforts, and aligns with the vision of an intelligent university. The architecture of this proposed technology encompasses three distinct layers, as depicted in Figure 5. We provide a detailed description of each layer (see Figure 5 in the appendix).

a) IoT Layer:

At the foundational level (Layer 1), we integrate detection and communication capabilities into the physical elements of the building to prepare them for the Internet of Things (IoT). We employ microcontrollers, specifically the Raspberry Pi4, to oversee elements equipped with sensors and communication units. These elements are now capable of environmental detection and communication with other devices using Bluetooth or WiFi. In the context of a Smart Classroom application, multiple such elements may be present in close proximity.

b) Fog Computing Layer:

Moving up to the second layer (Layer 2), we introduce the Fog computing server, which is responsible for local decision-making based on sensor data. This layer manages data collection, filtering, and preprocessing, while also serving as an Internet gateway that effectively connects IoT to the Internet through a VPN.

c) Cloud Layer:

The highest layer (Layer 3) involves transmitting data from the Fog layer to the Cloud for storage and processing. Here, a database is maintained for the cloud server, which is utilized to control IoT devices from smartphones or computers.

d) Hardware and Software:

As previously discussed, various hardware modules are employed to make simple elements IoT-compatible. In this work, we have utilized the Raspberry Pi3 to implement all direct communications with devices, including data retrieval from the devices and sending control commands to them, within the context of a Smart Classroom. Communication procedures between interfaces and protocols such as TCP/UDP, Inter-Integrated Circuit (I2C), Serial Peripheral Interface (SPI), General Purpose Input Output (GPIO), RS422/485/232, Modbus, Bluetooth Low Energy (BLE), RFID, and ZigBee need to be implemented on the Raspberry Pi within this layer. All programming languages supported by Raspbian can be employed to implement communication procedures.

All defined operations have been implemented as web service calls using Python and Flask on Raspberry Pi boards. When a basic operation of the Smart Classroom, such as turning off the air conditioning, is invoked via the web service call, the underlying control commands to the devices related to the operation will be invoked through the corresponding Flask route. Sensors or devices with the same function may have different control protocols or communication standards in Layer 2. With Layer 2, a function, such as turning on air conditioner number 1, can be defined as a basic operation for each Smart Classroom and implemented as a unified web application interface. Consequently, even if air conditioners in Smart Classrooms have different control protocols, central control applications can still turn on air conditioners in all Smart Classrooms by sending a unified web application interface call with parameters such as classroom identifier.

Basic operations are recorded in the database in Layer 2. Therefore, teachers, administrators, and software developers only need to focus on developing high-level or complex Smart Classroom applications, such as artificial intelligence applications, in Layer 4. For example, if a teacher develops context-aware applications for Smart Classrooms under the proposed architecture, the teacher can obtain sensor data through standard web application interface calls defined in Layer 3 and provide the retrieved data to the self-developed application in real-time. When the context-aware application decides to control certain devices in Smart Classrooms, corresponding operations can be initiated via the corresponding defined web application interface calls in Layer 3. The teacher does not need to be concerned with control details in Layer 1.

This layered architecture ensures a clear separation of concerns, making it easier for developers and users to interact with and leverage the capabilities of the Smart Classroom environment.

Shifting our discussion from the intricate smart classroom layout we previously discussed, we now venture into the realm of MQTT architecture. Earlier, our emphasis lay on constructing a layered architecture, emphasizing IoT device integration and cloud-centric control mechanisms. This structure was aimed at creating an organized blueprint for effective smart classroom management, delineating specific roles and focusing on proficient supervision and control.

Transitioning to the MQTT architecture, we pivot to examine its role as a messaging protocol. Contrary to the broader IoT and smart classroom context, MQTT stands out as a communicative tool within the client/server paradigm, ensuring fluid inter-device communications. Given MQTT's streamlined and resource-efficient nature, it's invaluable for IoT-driven endeavors, including the establishment of intelligent settings like smart classrooms.

Therefore, connecting the two sections, while our prior discussion highlighted the structural and operational intricacies of the smart classroom, our exploration of MQTT underlines the pivotal role communication protocols play. MQTT acts as the bridge, ensuring seamless interaction between various devices and components, reinforcing the functional coherence of the intelligent classroom ecosystem.

6. MQTT ARCHITECTURE: A DEEP DIVE INTO THE CLIENT-SERVER MODEL AND ITS COMPONENTS

MQTT operates on a client/server model. Within the MQTT paradigm, any device that employs TCP for establishing a connection to a server is termed a "Broker". Each message relayed by a Broker in MQTT represents a distinct piece of ambiguous data, reinforcing the fact that MQTT is fundamentally a message-oriented protocol. The specific address to which a message gets dispatched is termed its "Topic". Devices have the flexibility to subscribe to multiple topics and are recipients of all messages disseminated under these topics [44].

The MQTT protocol, a cornerstone in IoT communication, operates with a unique set of dynamics. Central to this is the client/server model, a foundation upon which MQTT establishes and manages its communications.

6.1 MQTT Client Dynamics

MQTT clients encompass a broad spectrum and aren't solely restricted to physical devices; they can be any IoT object engaged in the transmission or reception of data. Essentially, a client might range from a microcontroller to a full-fledged server. The specific nature of an MQTT client is contingent upon its role in the system, be it as a subscriber or a publisher.

6.2 The Role of the MQTT Broker

Sitting at the heart of MQTT communications, the Broker shoulders vital responsibilities. Its primary duties revolve around mediating communications amongst clients and apportioning messages based on the topics resonating with each client. Brokers are engineered to handle thousands of simultaneously connected devices. Upon receipt of a message, the Broker's task is to scout for all devices subscribed to the relevant topic.

MQTT's architectural blueprint is tripartite, encompassing a publisher, a broker, and a subscriber. Devices intrigued by specific topics enlist themselves as subscribers to be apprised when a publisher disseminates its topics via the Broker.

Through the intermediary of the Broker, the publisher disseminates information to the subscribers, who represent the entities expressing interest in the data. The publisher acts as the data source, post which the Broker affirms the concurrence between publishers and subscribers, ensuring an understanding of the intertwined security intricacies.

The constituents of the MQTT architecture are vividly illustrated in Figure 6, which provides a holistic view of its components.

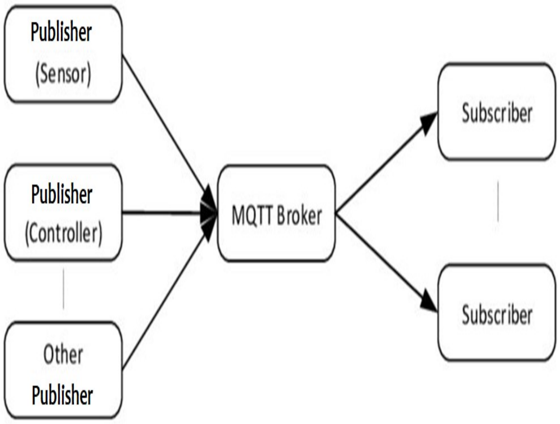


Figure 6: Components of the MQTT Architecture

Delving a step deeper, Figure 7 showcases the implemented MQTT architecture, highlighting the intricate relationships and workflows between the different entities.

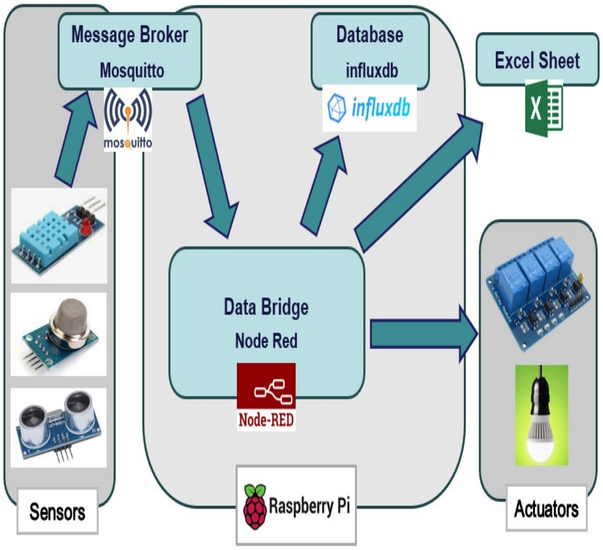


Figure 7: Implemented MQTT Architecture

Transitioning from MQTT's foundational principles to its practical applications, the significance of this robust messaging protocol becomes especially apparent in the realm of Smart Classroom temperature management. Given MQTT's broker-centric architecture, it is uniquely positioned to effectively handle the myriad of IoT devices that are integral to monitoring and controlling classroom temperatures. The protocol's efficiency and security protocols become invaluable when dealing with real-time data streams, ensuring that the Smart Classroom environment remains both adaptive and responsive to its occupants' needs. As we delve deeper into Section 7, the practical implications of MQTT in monitoring and controlling Smart Classroom temperature will become increasingly evident, showcasing its critical role in creating an optimal learning environment.

7. MONITORING AND CONTROL OF SMART CLASSROOM TEMPERATURE

7.1 Enhanced Thermal Comfort through IoT Integration and Fuzzy Logic Control

Thermal comfort, a vital aspect of indoor environments, is determined by a myriad of factors ranging from ambient temperature and humidity to individual preferences and clothing. In recent years, the rapid evolution of technology and the surge in data analytics have given rise to a plethora of algorithms and software tools specifically tailored to address the challenges of ensuring optimal indoor comfort. Among these advancements, the integration of Internet of Things (IoT) devices has emerged as a transformative approach.

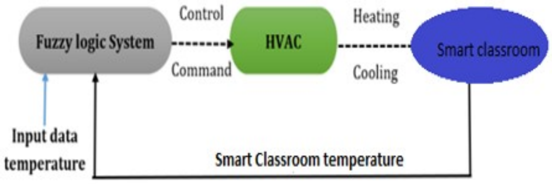
One of the notable implementations in this domain is the application of a fuzzy controller designed to cater to the nuanced needs of Smart Classroom occupants. This system leverages the capabilities of IoT sensors, effectively becoming the nexus between the classroom's inhabitants and the environment. Such a configuration ensures that occupants, whether students or faculty, are relieved from the mundane concerns about the indoor temperature. Their focus remains undiverted, trusting the automation to maintain a conducive learning atmosphere.

A crucial element in this setup is the HVAC (Heating, Ventilation, and Air Conditioning) system, which, in conjunction with an advanced energy management system, synchronously operates with IoT sensors. This integrated mechanism is vigilant, continuously monitoring various parameters like temperature, humidity, and air quality, thereby ensuring a seamless and adaptive response to any changes in the indoor environment [45].

The genius behind this automation is the fuzzy controller, which is meticulously constructed upon a set of well-defined rules. These rules are not rigid binary conditions, but rather, they operate on a spectrum, allowing for greater flexibility and adaptability. By employing policies articulated in if-then-else constructs, the system can make informed decisions that not only ensure optimal thermal conditions but also promote energy efficiency. This dual advantage is pivotal, especially in the context of growing concerns about energy conservation and Sustainability.

To ascertain the robustness and efficiency of the fuzzy logic system, the input datasets, which are primarily sensor readings, are processed through a verification software. This software serves as a validation checkpoint, assessing the precision of the system's outputs. One of the primary metrics under scrutiny is the stability of the indoor temperature, which is a direct reflection of the system's efficacy.

The meticulous application of this control algorithm, bolstered by the synergy of IoT and fuzzy logic, emphasizes the core aim of our



academic exploration. Our intent is to sculpt a vision for smart classrooms, where judicious energy utilization coexists with unmatched indoor ambiance, all rooted in the abundant data insights gathered from IoT sensors within these educational spaces. This methodology not only signifies a transformative shift in how classrooms are managed, but it also elevates the standards for designing sustainable and digitally enhanced learning environments through the efficient use of HVAC systems.

7.2 The proposed system

The quest for achieving consistent and reliable thermal comfort in indoor environments is an ongoing challenge faced by building engineers and architects. Among the various techniques employed to address this challenge, fuzzy logic emerges as a particularly promising solution. Rooted in the principles of mathematical logic and set theory, fuzzy logic provides a structured yet flexible framework for managing complex systems, especially in situations where precise data may be lacking or variables are inherently ambiguous.

At its core, the fuzzy logic technique is a method to ensure dependable thermal comfort, which entails intricate control of the building's energy system. This control encompasses both the heating and cooling mechanisms, optimizing them to achieve a balance that caters to human comfort while ensuring energy efficiency. Unlike traditional binary systems that operate in absolutes (on/off, hot/cold), fuzzy logic thrives in the gray areas, allowing for nuanced adjustments that can adapt to a spectrum of conditions and preferences.

Within the context of a smart classroom, the decision to activate or deactivate the HVAC (Heating, Ventilation, and Air Conditioning) system doesn't solely hinge on traditional parameters. Instead, it intertwines predefined regulations with behavioral patterns exhibited by the classroom occupants. For example, on a slightly chilly day, rather than just switching the heating system on or off based on temperature alone, fuzzy logic in an intelligent classroom might modulate the system's intensity. It would take into account factors such as the number of students present, the general activity level in the class, or even the type of clothing they are wearing. This nuanced approach ensures optimal thermal comfort while maintaining energy efficiency.

Figure 8: Fuzzy Logic for HVAC

Figure 8 introduces an intricate approach to the fuzzy logic system tailored for the intelligent classroom environment. The system's architecture is visually depicted, starting from the left side, which is dedicated to gathering input data from the ambient environment, mainly focusing on degrees (temperature readings).

Upon collecting this data, a process of fuzzification occurs. This process translates the crisp, numerical temperature readings into fuzzy sets or linguistic values. Consequently, the HVAC system, based on the directives received from the fuzzy algorithm, is informed about the appropriate course of action. It's essential to highlight that the HVAC system's operation, whether to heat or cool the environment, directly impacts energy consumption. However, this action is only undertaken after juxtaposing the current reading with the initial indoor temperature value.

The system's foundation is a Python code that leverages fuzzy logic to meticulously control the heating and cooling temperatures based on two primary variables: room temperature and humidity. The parameters are defined as:

Temperature: Room temperature, which can range from 0 to 100 degrees Celsius.

Humidity: Room humidity levels, ranging from 0% to 100%.

The resultant output is:

Power: Determining the heating or cooling intensity, fluctuating between 0% to 100%.

For an accurate representation of these variables, fuzzy membership functions are employed using the trimf() function from the renowned scikit-fuzzy library. These functions help in mapping the crisp values into fuzzy sets. Fuzzy rules, which are the essence of the fuzzy logic system, are articulated using logical operators like AND and OR, setting clear conditions under which the heating or cooling power should be adjusted.

With these rules in place, a control system is instantiated. This system, upon initialization with temperature and humidity values, calculates the required heating or cooling power using the compute() function from the ControlSystemSimulation class.

This intricate system is further elucidated visually in Figures 9 and 10. These graphs illustrate the membership functions, providing insights into how the input variables, temperature and humidity, correlate with distinct fuzzy sets. These sets shed light on how much the input values resonate with specific categories or labels like "cold," "comfortable," or "hot" for temperature, and "dry," "ambient," or "humid" for humidity.

The output variable, power, is similarly mapped onto fuzzy sets, indicating the resultant power level based on the temperature and humidity readings. The fuzzy sets for this output variable are categorized as "low," "medium," and "high."

In summation, this comprehensive fuzzy logic system offers a nuanced approach to intelligent classroom climate control, ensuring optimal thermal comfort, energy efficiency, and a responsive environment that adapts to varying conditions. It stands as a testament to the seamless fusion of technology and human comfort, paving the way for sustainable and intelligent infrastructure design.

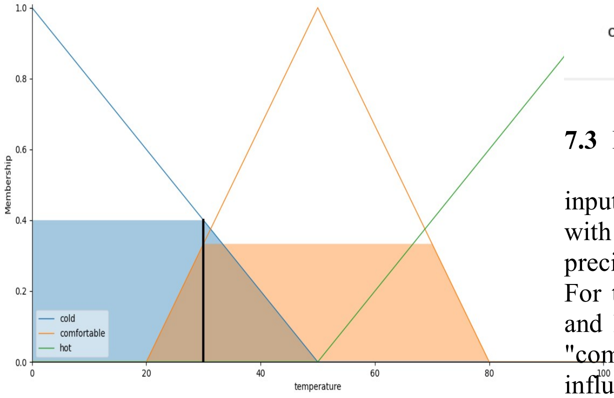


Figure 9: Membership function of temperature

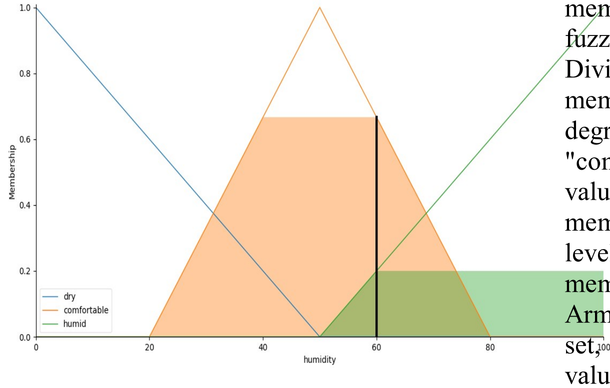


Figure 10: Membership function of humidity

The output variable, power, is also mapped onto fuzzy sets, indicating the level of output power based on the input values of temperature and humidity. The fuzzy sets designated for the output variable include "low," "medium," and "high." As illustrated in Figure 11, the fuzzy logic system appears to be operating optimally. It adeptly matches the input values to the corresponding fuzzy sets and predicts the output power based on the established rules and membership functions. Overall, this system showcases the efficacy of fuzzy logic in accurately predicting and adjusting the energy output, ensuring a harmonious balance between energy conservation and user comfort. as shown in figure 11.

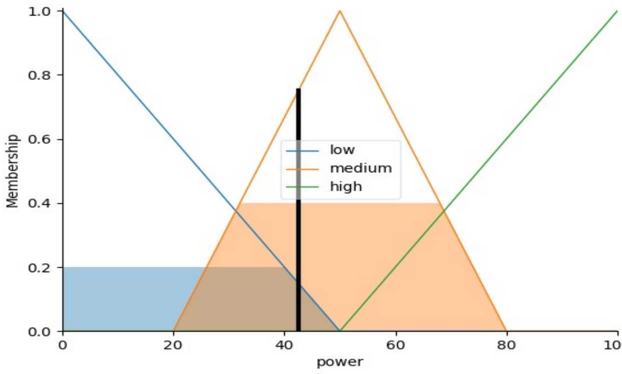


Figure 11: Power Membership Function.

7.3 Results and discussion

The simulation insights, derived from an input temperature of 30 degrees Celsius combined with 60% humidity, illuminate the efficacy and precision of the fuzzy logic system in operation. For the provided parameters, both the temperature and humidity found themselves nestled within the "comfortable" category. This classification directly influenced the system's determination that the output power should be situated within the "medium" bracket, a decision further ratified by the membership function associated with the "medium" fuzzy set for the output.

Diving deeper into the analysis, the temperature membership function's graph underscored that a 30-degree value is squarely positioned in the "comfortable" domain, registering a membership value of 0.5. In a parallel manner, the humidity membership function designated the 60% humidity level as "comfortable", reflecting an identical membership value of 0.5.

Armed with these inputs and the established rule set, the system adroitly projected an output power value of 50, resonating with the "medium" category, as depicted on the power membership function graph.

The subsequent coding phase harnessed the output derived from the fuzzy logic controller to pinpoint the optimal room temperature. The parameters were judiciously set: for an output power less than 30, the temperature was set to a brisk 18 degrees Celsius; if it ranged between 30 and 70, a moderate 22 degrees Celsius was chosen; and for values exceeding 70, a warmer 26 degrees Celsius was deemed appropriate. Once processed, this desired temperature data was broadcasted to

AWS IoT via an MQTT client, following which the system executed a server disconnect.

A standout feature of this framework is its inherent adaptability. The algorithm can be fine-tuned for specific scenarios by modulating membership functions, adjusting rules, recalibrating output variables, and even redefining the MQTT client's connectivity parameters. Additionally, the desired temperature thresholds can be modified to cater to unique requirements.

From the results, it's clear that the HVAC system's adaptability allows its power output to shift responsively according to nuanced room conditions such as temperature and humidity. This adaptiveness, rooted in the detailed coordination of fuzzy membership functions and rules, ensures enhanced occupant comfort. However, it's crucial to recognize the occasional code errors, possibly due to specific time constraints, indicating a call for further refinement.

Figure 12 offers a visual representation of the physical prototype and its activation for real-time data acquisition. The subsequent illustration unveils an interactive real-time control interface, dynamically showcasing real-time data points, including the intelligent classroom's temperature and humidity, along with the heating and ventilation system metrics.

The implementation of the system (see Figure 12 in the appendix).

This study underscores the transformative potential of such intelligent systems in contemporary infrastructure, emphasizing the need for continuous innovation and refinement. The observations and conclusions drawn pave the way for more advanced implementations and broader applications in varied settings as shown in figure 13.

(See Figure 13 in appendix)

8. CONCLUSION

This paper presents a cohesive and forward-thinking approach to addressing the challenges and harnessing the opportunities presented by urbanization and Sustainability in the educational sector. At the heart of this transformation is the concept of the Smart University, a paradigm shift in educational infrastructure powered by the integration of the Internet of Things (IoT) and fuzzy logic control.

Through a comprehensive exploration of existing IoT applications in various sectors and the potential of fuzzy logic, we have highlighted the immense possibilities these technologies hold for revolutionizing educational environments. The journey from traditional classrooms to innovative, interactive spaces signifies a new era in education, marked by enhanced customization, efficiency, and Sustainability.

Our study has mainly focused on the pivotal role of IoT in transforming educational spaces. By integrating IoT with fuzzy logic, we propose a Smart University model that addresses the critical challenge of real-time data analysis. This model, underpinned by Fog and Edge computing, is not only innovative in enhancing thermal comfort in classrooms but also redefines the management and optimization of these learning spaces.

However, this journey is not without its challenges. The implementation of IoT systems involves considerations of cost, complexity, and security, alongside the need for regular maintenance and data management. Despite these challenges, the potential benefits in terms of efficiency and Sustainability are significant.

The results from our simulations demonstrate the precision and effectiveness of the proposed fuzzy logic system in maintaining optimal thermal comfort. The adaptability of this system is a key feature, allowing for fine-tuning to specific environmental conditions and user requirements.

Furthermore, the physical prototype and its real-time data acquisition system, as illustrated in the appendices, showcase the practical application of our proposed model. This implementation not only serves as a proof of concept but also opens the door to wider applications in different educational settings.

In conclusion, this paper not only provides a theoretical framework for the integration of IoT and fuzzy logic in Smart Universities but also lays the groundwork for future research and development in this field. The need for continuous innovation, refinement, and adaptation is paramount. As we look ahead, the potential for these technologies to create sustainable, intelligent, and comfortable learning environments is immense. This research underscores the importance of sustained effort in this domain, propelling us towards a future where Smart Universities are a cornerstone of intelligent urban landscapes.

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APPENDIX

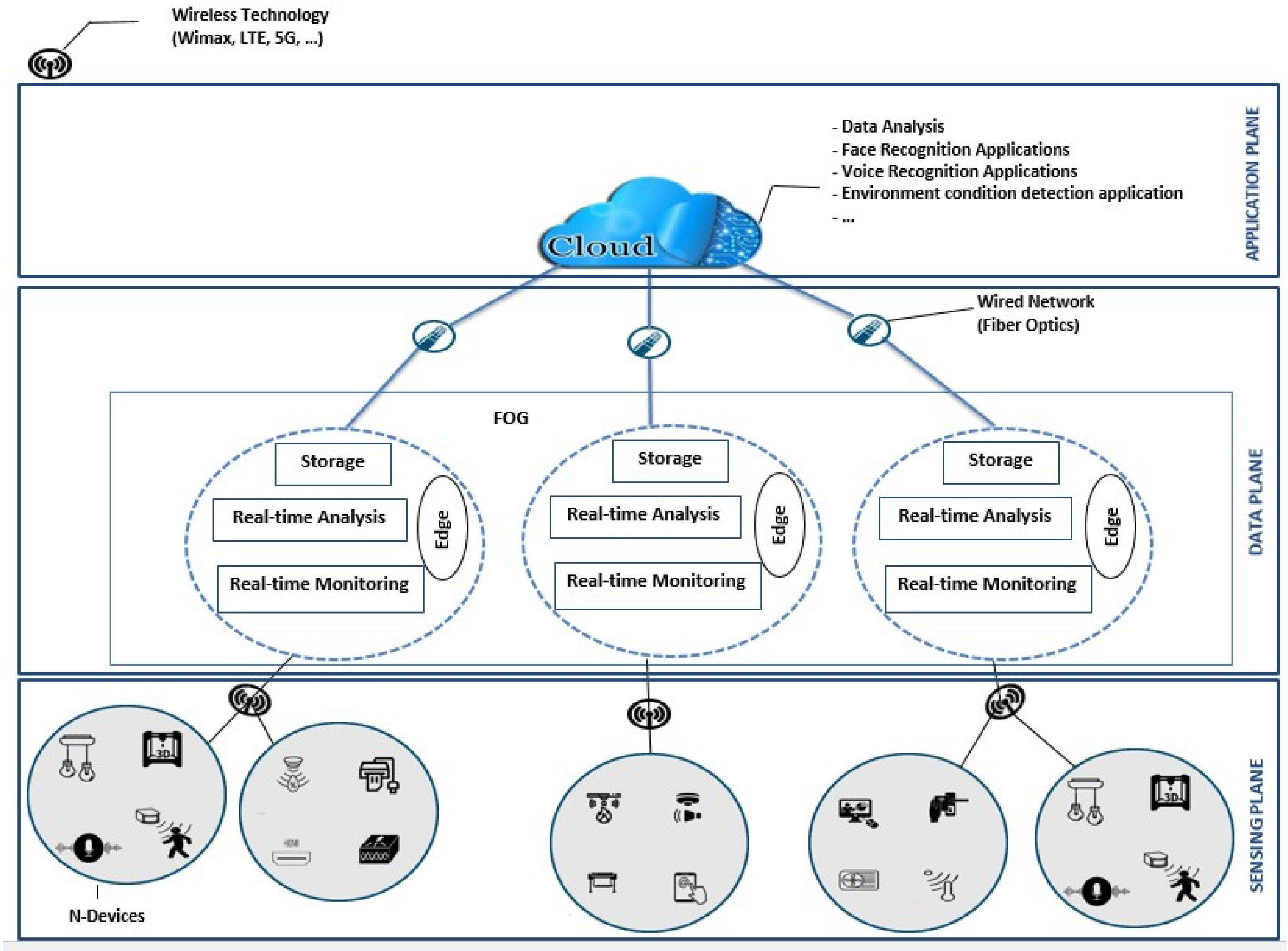


Figure 4: Smart University architecture

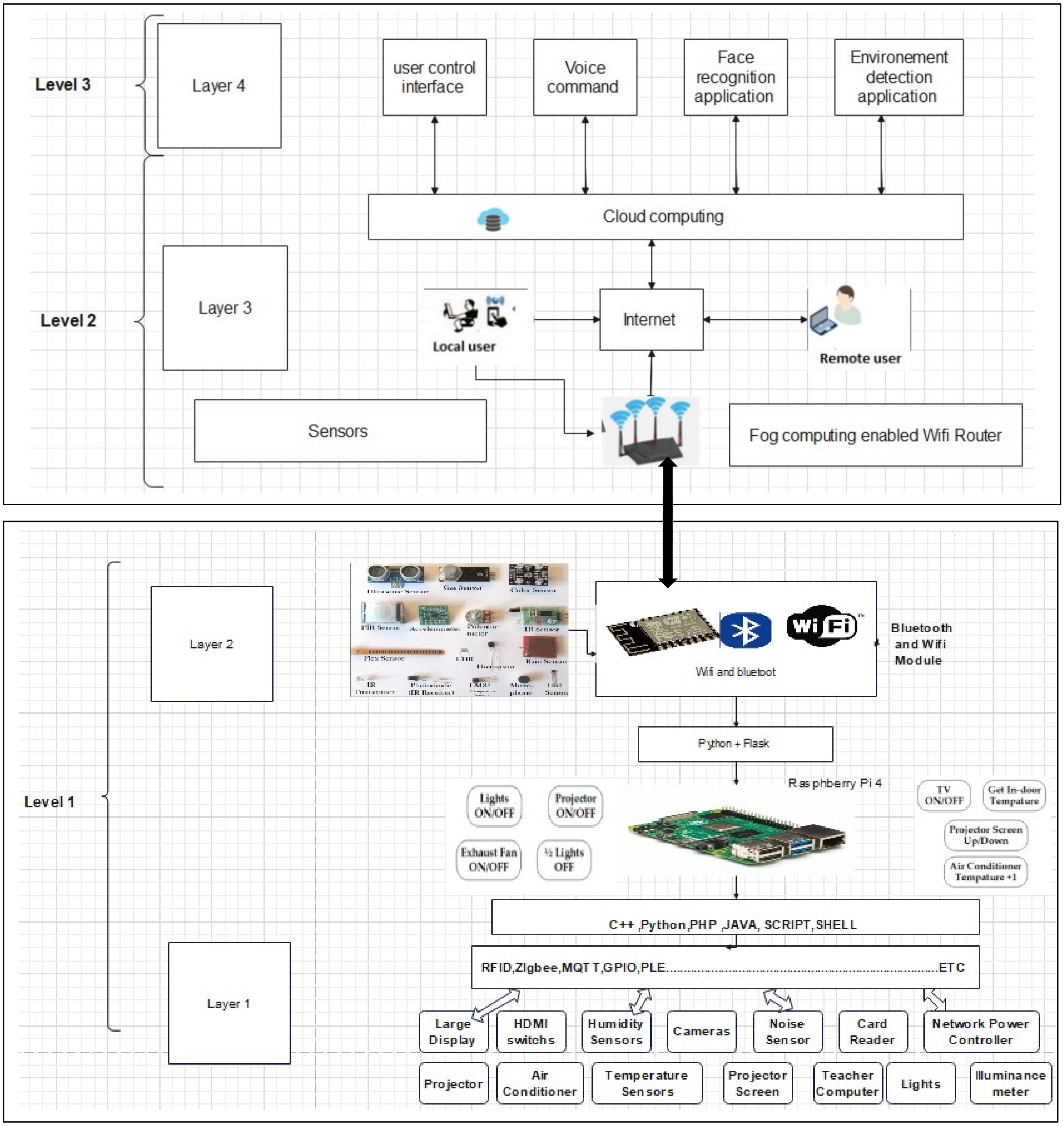


Figure 5: Smart Classroom Architecture

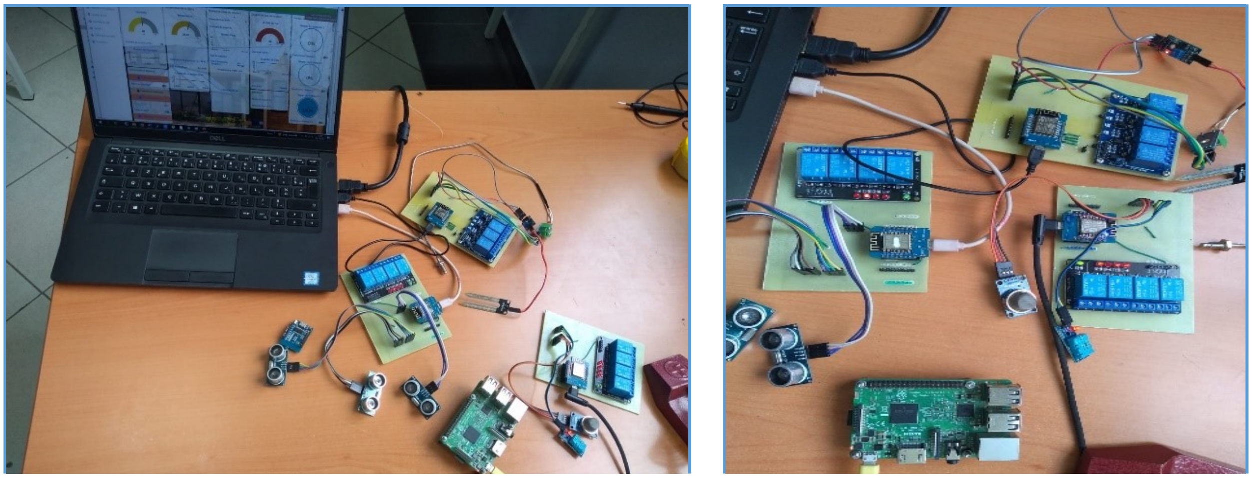
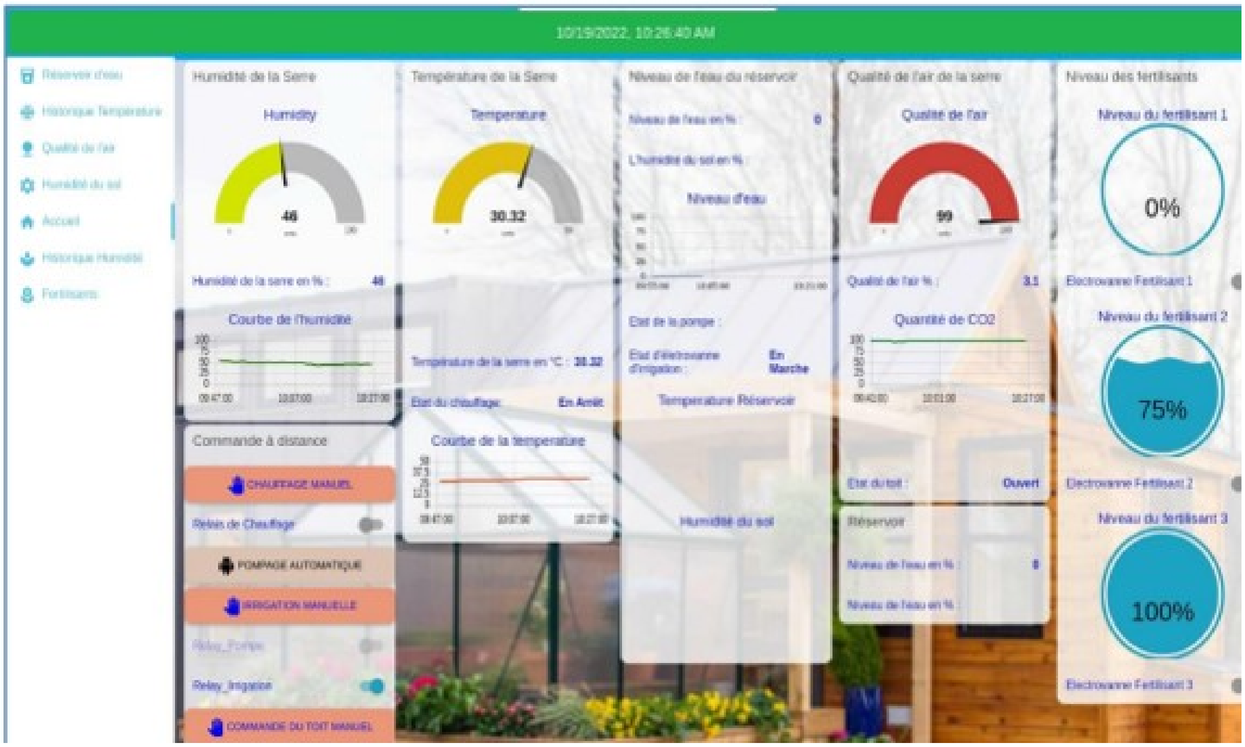


Figure 12: The implementation of the system.



Humidité de la serre en % : 46

Relais de Chauffage

Relay_Pompe

Relay_Irrigation

Température de la serre en °C : 30.32

Etat du chauffage : En Arrêt

Niveau de l'eau en % : 0

L'humidité du sol en % :

Etat de la pompe :

Etat d'électrovanne d'irrigation : En Marche

Qualité de l'air % : 3.1

Etat du toit : Ouvert

Niveau de l'eau en % : 0

Niveau de l'eau en % :

Electrovanne Fertilisant 1

Electrovanne Fertilisant 2

Electrovanne Fertilisant 3

Figure 13: Dashboard deployed using the Node.JS script.