Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 198 (2024) 126-138 EISSN 2392-2192

Internet of Things Based Home Automation Along With Facial Detection and Recognition

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ABSTRACT

The Internet of Things (IoT) represents an emerging paradigm that emphasizes the interconnectedness of devices and their communication with users. This technology is anticipated to play a pivotal role in the development of smart homes, enhancing both quality of life and household efficiency. This article considers the development of a home automation system leveraging IoT technology, with key features including a custom mobile application, facial detection and recognition systems, and an integrated temperature notification and management system. In the article, a description of how an IoT home automation system is established was considered, alongside the equipment utilised in setting up the system such as NodeMCU and ESP32-CAM with a reliable connection to Firebase for the exchange of data. Further, the process covering the facial recognition feature for enhanced security is discussed. The entire home automation system is strongly supported by the Firebase application which provides two-way communication between the microcontroller and the mobile application for effective control and interaction with the home appliances. With full simulation, it was concluded that while the project addresses energy needs, further advancement can be made by implementing Machine Learning models for a more efficient and automated process.

Keywords: Internet of Things (IoT), Home Automation, Flutter, Firebase, Facial recognition.

(Received 5 September 2024; Accepted 1 October 2024; Date of Publication 29 November 2024)

1. INTRODUCTION

Among the various definitions of automation, one of the most prominent describes it as the technique or system of controlling processes with minimal human intervention, typically using electronic devices. Automation finds applications across numerous industries, including home automation, which is designed to simplify and enhance daily life [1]. Home automation involves creating systems that manage and control household functions such as lighting, climate, entertainment, and appliances, offering greater convenience and comfort.

Controlling aspects of the house, such as the lighting, is crucial for energy efficiency. All human endeavours require energy, which is also crucial for social and economic advancement [2]. Demand for energy is significant because it impacts the economy, which impacts people's lives (i.e., their income, health, and happiness), as well as their capacity to meet necessities like infrastructure, education, and so forth [2]. In today's society, automation—such as residential and industrial automation, among others—has grown in importance since it makes tasks easier to accomplish and more intelligently. Since internet-enabled devices can improve home automation, the Internet of Things is made up of all home appliances and devices connected to the internet.

The Internet of Things (IoT) is a concept that enables the creation of a wireless network among various devices, accessed via the internet and diverse IP protocols. As the demand for internet connectivity grows, so does the demand for IoT. According to Garg and Gupta [3], IoT-based devices and appliances help save time by allowing users to control their devices remotely from any location. Essentially, IoT forms an ecosystem of interconnected devices, such as sensors, microcontrollers, and mobile phones, that communicate over wireless networks [4]. IoT facilitates the exchange of data between physical objects equipped with necessary technologies and other devices or systems over the internet or other networks (e.g., localhost). Integrating IoT into home automation expands its capabilities, making smart homes more efficient and versatile. Since its inception, IoT has been woven into many aspects of daily life, offering simplifications that are highly beneficial and cannot be overstated.

Home automation is a concept centered on the efficient monitoring and control of household systems. This study presents an internet-based home automation system that integrates facial recognition technology and a PIR sensor to optimize energy consumption and management. It specifically aims to address the issue of energy management in a country like Nigeria, which faces significant energy shortages and conservation challenges. Additionally, the study demonstrates how easily appliances can be controlled from any location and monitored through a security-enabled camera, all accessible via a Flutter-based mobile application. The methodology employed to achieve this is detailed in the following sections, with key conclusions and recommendations for future research provided.

The project was developed to address several critical concerns, including the safe control of home appliances to prevent electrical shocks, the monitoring and prevention of fire hazards, efficient energy management, and the enhancement of home security.

2. LITERATURE REVIEW

The term "Internet of Things" (IoT) was first coined by Kevin Ashton during a presentation in 1998 [5]. According to Vermesan, O. et al. [6], IoT enables seamless connectivity between people and objects at any time, from any location, using any network and service. The expansion of IoT has increasingly integrated into everyday activities and simple household appliances. Automated homes are becoming more prevalent due to their numerous benefits, including enhanced security, efficient energy use and savings, improved accessibility, and convenient control of household devices, among others.

2.1. Internet of Things Concept

IoT devices can access aggregated information and participate in more complex services [7]. As noted by Awati and Wigmore [8], a "thing" in the Internet of Things can be anything from a person with a heart monitor to a farm animal with a biochip transponder, or even a car equipped with sensors to alert the driver of low tire pressure. Essentially, any natural or man-made object assigned an Internet Protocol (IP) address and capable of transmitting data over a network qualifies as a "thing." IoT can be described as a system of interconnected electronic devices, sensors, actuators, and software, linked via Wi-Fi, allowing these objects to exchange information. In this paper, this concept is implemented using NodeMCU, a mobile application, Firebase, and various loads.

IoT involves collecting, processing, and analyzing data, with the collected data transmitted from devices to a central point. This transmission can be wireless, utilizing various technologies, or through wired networks. The data may be sent over the internet to data centers or cloud systems with storage and computing capabilities, or staged through devices that aggregate the data before further transmission. IoT technologies are versatile and adaptable, making them applicable in a wide range of fields by providing crucial information on the performance of activities or environmental conditions that require remote monitoring and control. IoT is increasingly used to simplify, enhance, automate, and control numerous processes. Some key areas of IoT application include:

- Agriculture
- Wearable Technology
- Health Care
- Home Automation

2.2. Review of existing research on home automation system

Over time, various research projects and designs in home automation have demonstrated the control of household appliances and more. Patchava et al. [9] developed a smart home automation system that integrated motion sensors and video cameras for surveillance, sending alerts to homeowners via SMS and alarm calls. Gabhane et al. [10] implemented a system for controlling three electronic devices—television, fan, light, and gas outlet—to showcase the application of smart home technology. In the work of P. Eben et al. [11], lights were controlled using PIR sensors that detected human proximity, automatically switching the lights on and off based on sensor data. They also used a transfer module to control main voltages, displaying the data on an LCD, with the entire system connected and controlled via the web.

Govindraj et al. [12] utilized various sensors, including a light detector, temperature sensor, motion detection sensor, capacitive touch sensor, and gas sensor, to efficiently control and monitor electrical home appliances. The data from these sensors were transmitted to a satellite station and used to control devices such as lights, fans, and relays. Bhagyamma et al. [13] combined both Raspberry Pi and Arduino UNO in their home automation system, where Arduino UNO controlled devices and collected sensor data, while Raspberry Pi processed the sensor data. Each room featured multiple controllable devices like lights, fans, and wall sockets, with PIR sensors detecting human presence and LDR sensors measuring light intensity.

Ranjithkumar et al. [4] used the Blynk app, connected to a Wi-Fi module (ESP8266), to control devices, while Rahul et al. Ranjan et al., [1] implemented voice control using PIR and voice recognition sensors, programming the sensors with the “VoiceRecognitionV3.h” header in Arduino.

However, none of these studies incorporated a custom-designed application with facial recognition and detection, a gap that this study addresses effectively.

2.3. Development Boards

To implement a home automation system using IoT, integrating a development board is essential. It facilitates direct communication with and control of the sensors while also transmitting processed data to the designated storage server. Some of the most commonly used development boards include:

- **Raspberry Pi**

  The Raspberry Pi is a series of compact single-board computers developed by the Raspberry Pi Foundation in the United Kingdom. It functions as a mini-computer when connected to peripherals like a keyboard and monitor. Raspberry Pi is widely used in real-time processing, IoT applications, robotics, and more. In the home automation system designed by Bhagyamma et al. [13], both Raspberry Pi and Arduino Uno were utilized, with the Raspberry Pi processing sensor data and transmitting it to the cloud, allowing users to access the information remotely from any location.

- **Arduino**

  Arduino is an open-source electronics platform designed for easy-to-use hardware and software. It operates by programming the microcontroller on the board using the Arduino programming language and the Arduino Software (IDE). P. Eben et al. [11] utilized an Arduino Uno to control sensors and electrical devices. In their system, the Arduino receives signals from a PIR sensor and activates lights, fans, or other appliances. The Arduino checks the PIR sensor signals every 40 seconds, keeping the devices on when the output is '1' (high) and turning them off when the output is '0' (low). Similarly, Wadhwani et al. [14] employed Arduino Uno to control sensors, with the data monitored through the cloud. The sensors' readings trigger changes in the status of connected appliances, which are controlled based on sensor values.

- **NodeMCU**

  The NodeMCU is an affordable, open-source platform designed for IoT applications. Its popularity stems from its low cost combined with built-in Wi-Fi capabilities, making it a highly efficient choice for IoT projects.

Madhu and Vyjayanthi [15] developed a home automation system using NodeMCU to control household appliances by sending and receiving data through HTTP requests from an Android mobile app. Similarly, Singh et al. [16] implemented a home automation system that uses relays connected to a NodeMCU to remotely control electrical switches via a web application and a server built with Node.js.

2.4. Facial Recognition

According to Li et al. [17], studies on how to make machines recognize faces began in the 1950s, with the applied research of face recognition beginning in 1964. Face recognition broadly encompasses related technologies for constructing a face recognition system. This includes face detection, face position, identity recognition, image pre-processing, etc. The concept of facial recognition is the process of scanning the entire image to determine whether the candidate area is a face. Face recognition technology is widely applied in attendance access control [18], security [19] and finance, while many other fields are starting to get involved such as logistics, retail, smartphone, transportation, education, real estate [20].

Li et al. [17] finds that in the field of security, through the assistance of face recognition, both the early warning of suspicious situations and the trace of suspects can be solved. Li & Jain [21] posit that along with rising public concern for security, there are several reasons for recent increased interest in face recognition, such as the need for identity verification in the digital world, and the need for face analysis and modelling techniques in multimedia data management and computer entertainment achieved by implementation of the facial recognition system in several social places.

3. SYSTEM DESCRIPTION

This chapter examines the key components and processes involved in designing and building an IoT-based home automation system with facial detection and recognition capabilities. It covers the hardware used in the project, including the PIR sensor, ESP32-CAM, and NodeMCU, among others. Additionally, the chapter discusses the software tools utilized for design, implementation, and programming, such as Fritzing, Fusion 360, Arduino, Flutter, and Firebase.

3.1. Hardware Components

Various hardware components were utilized in achieving this study, some of the key hardware components include:

- **Relay**

A relay is a switch that open and close circuits electromechanically or electronically. Relays are either electromechanical relays or solid-state relays. A relay has two states: normally open or normally closed. When the relay is of normally open contacts, there is a closed contact when the relay is energized, while when it is normally closed, there is an open contact when the relay is not energized. The relay is utilized in this design to switch the connected appliances between the off and on state using its normally opened contact.

- **NodeMCU**

The NodeMCU is an open-source firmware designed for prototyping and was developed using the Lua scripting language. It can also be programmed using Arduino C. There are two versions of NodeMCU available: version 0.9 and version 1.0, with version 1.0 being used in this project.

The NodeMCU serves as the microcontroller, enabling the control of appliances through the mobile application developed for the system.

- **PIR sensor (HC SR501)**

The Passive Infrared (PIR) sensor is an electronic device that detects infrared (IR) light emitted by objects within its range. PIR sensors use pyroelectric sensors to measure infrared radiation and are commonly employed to detect motion. They can be powered by any DC voltage between 4.5 and 12 volts, with 5 volts being the typical choice. The sensor consists of three pins: VCC, Output, and GND. In this project, the PIR sensor is used to facilitate energy conservation.

- **ESP32-CAM**

The ESP32-CAM is a compact, low-power camera module built around the ESP32. It features integrated Wi-Fi, allowing for the transmission and viewing of data collected by the camera over the internet. In this project, the ESP32-CAM is used within the facial recognition system, enhancing security.

- **Temperature and Humidity Sensor (DHT-11)**

The DHT-11 is a basic temperature and humidity sensor. The sensor works by sending signals of its continuous monitoring of temperature and humidity. The DHT-11 is used in this system to keep track of variation in temperature and notify the owner of the house.

3.2. Software Components

- **Arduino IDE**

It is an application that is used to write codes to the different variations of the Arduino board, also other Arduino compatible boards such as the Arduino Nano, NodeMCU, etc.

- **Android Studio**

This is an Android integrated development environment (IDE) used for creating mobile applications. It is the official IDE for Google's Android operating system, but it can also be used to develop mobile applications that function across other operating systems.

- **Flutter SDK (Dart Programming Language)**

Google developed this open-source user interface software development kit. Among other platforms, it may be used to develop cross-platform apps for iOS and Android. Flutter offers platform and code flexibility and convenience.

- **Firebase**

This is a backend system created by Google to host backend services for mobile application or web applications. Firebase was utilized to store the state of the appliances using real-time database.

- **Fritzing**

  This is a software application which is used in designing and simulating circuits, which can be implemented as a PCB before they are utilized. The circuit designs for this project was done using the fritzing application.

3.3. System Overview

The smart home automation system working process is such that the NodeMCU sends the data gotten from the PIR sensor and DHT-11 sensor as JSON data to the Firebase RTDB, which is then transferred to and displayed by the mobile application. The mobile application developed in Flutter has ”Light” and “Fan” navigation tabs, which have two buttons that turn the lights and fan ”ON” and ”OFF” when clicked. The “Status” navigation tab showed the current status of the bulbs, fan, PIR and DHT-11. If the status showed the value ”ON”, this means that the bulbs and fan were turned on. However, when the “OFF” button of either fan or light was clicked a JSON string holding a value of 0 for ”fan” and “light” attribute, {’fan’:0} and {’light’:0} is sent to the RTDB of the Firebase.

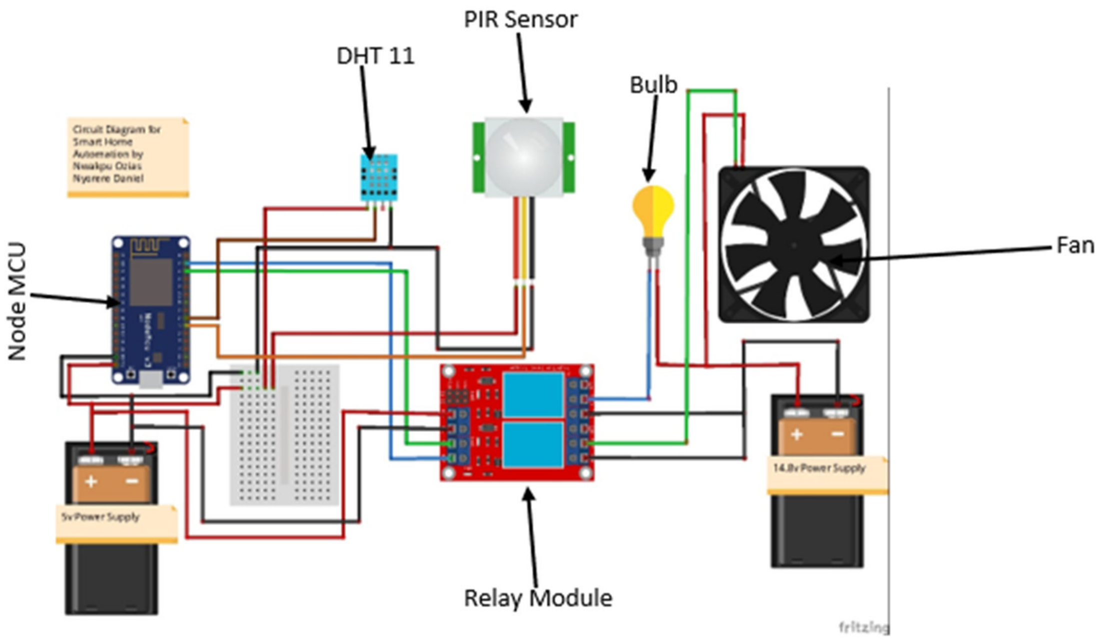

Figure 1. Circuit design of the Home Automation System

The JSON string received by this RTDB is then sent to its subscribers, the NodeMCU in this project's case. The NodeMCU then receives the JSON string, checking the "light" and "fan" attribute value and turns the bulbs and fan accordingly. The data sent and stored in the database is then transferred to and gotten by the NodeMCU thus controlling the appliances in either switched ON or OFF state.

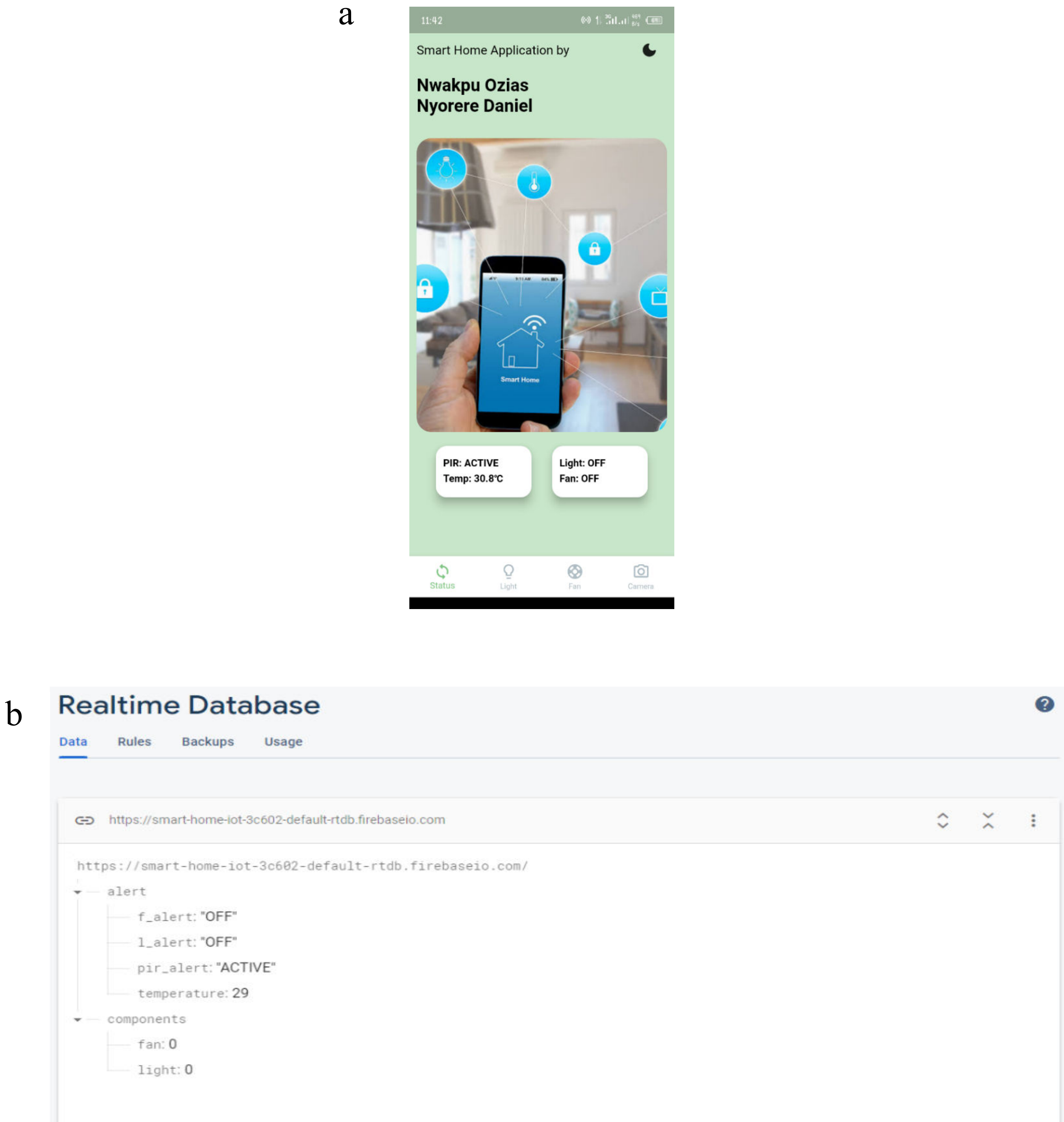

Figure 2 a-b. Status page of mobile application and real-time database showing data of the appliances

The facial detection and recognition working process is such that the ESP32-CAM, working according to how it is programmed, detects and recognizes a face and in turn send signal to solenoid lock. In the case whereby a face is recognized, the signal is sent to relay which in turn energizes the coil of the solenoid lock, unlocking the lock. Then after a 4000ms delay, the coil is de-energized, and the solenoid lock is back in the lock state. In the case where the face detected isn't recognized, the lock remains in its de-energized state as such the door remains closed.

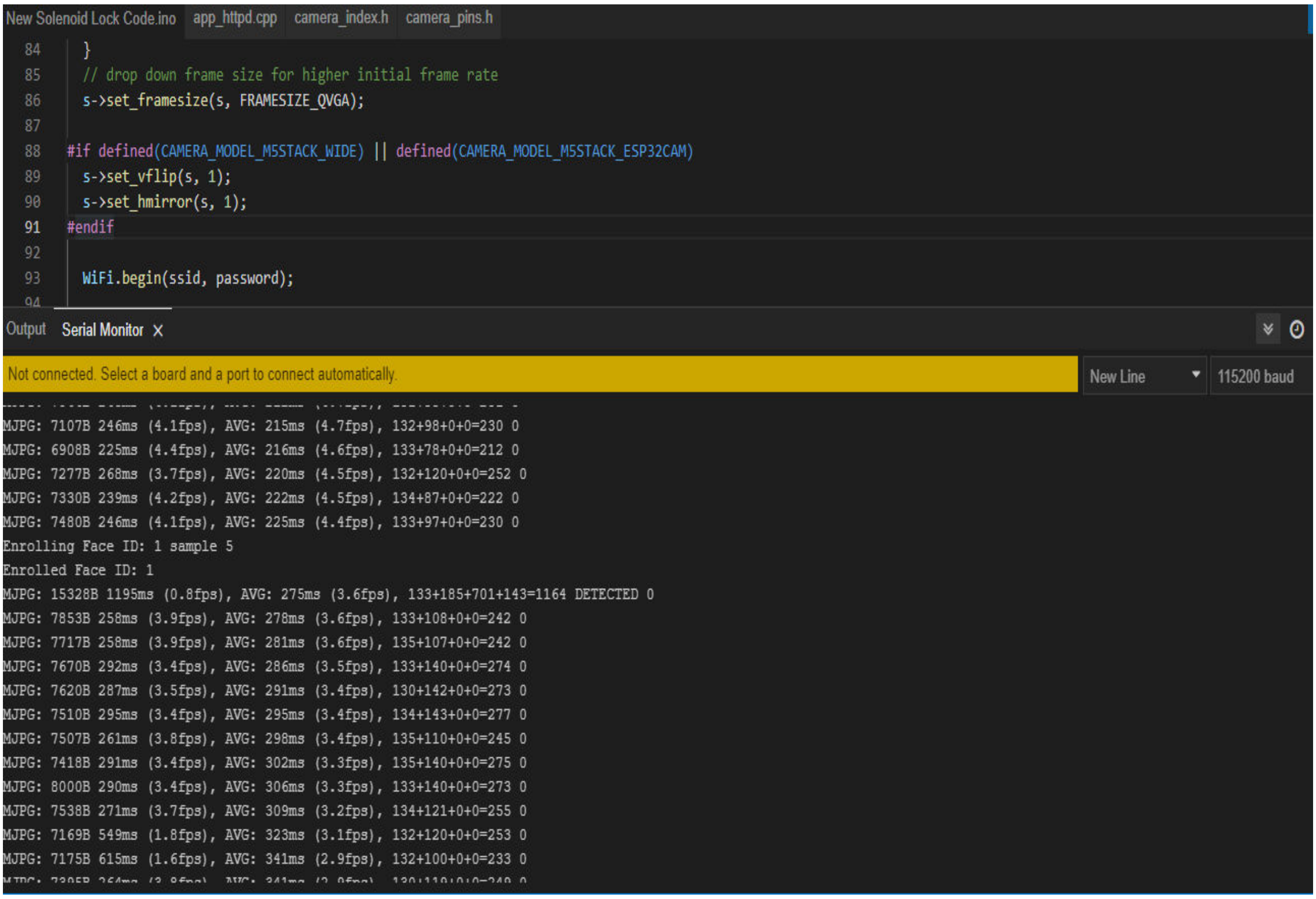

Figure 3. Serial monitor view of the camera enrolling 5 samples of a face

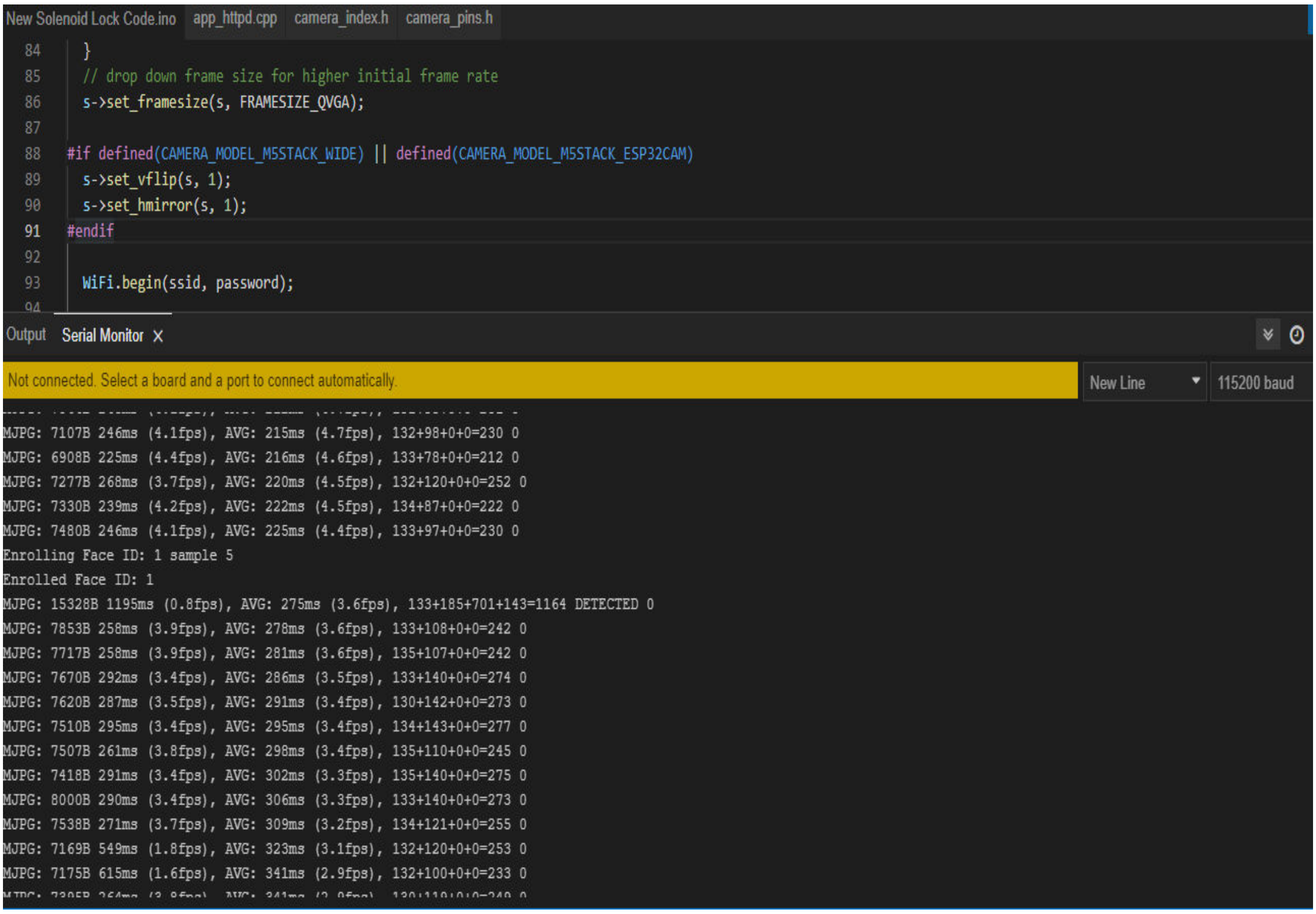

Figure 4. Serial monitor view of showing the facial recognition details

4. RECOMMENDATION

The following are recommendations for further studies:

- The use of machine learning algorithms can be introduced for a more efficient home automation system.
- Display of energy consumption using sensors for different appliances can be implemented in real-time on the mobile application.
- The project can also be implemented in a major household.
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5. CONCLUSIONS

This project effectively showcases the potential of integrating modern technology to improve convenience, energy efficiency, and security within residential environments. By leveraging IoT devices, smart sensors, and automation platforms, we have developed a system that centralizes control over household appliances, lighting, and security, enhancing the overall quality of life. The project underscores the increasing demand for customizable and scalable solutions to accommodate diverse user needs.

Looking ahead, future improvements can be achieved by incorporating AI-driven systems capable of learning and predicting user preferences, further enriching the automation experience. This project serves as a significant step toward the future of smart homes, laying the groundwork for more advanced innovations.

Appendix

The complete code for the project can be accessed on:

www.github.com/NDaneet/simple smart home control application

Statements & Declarations

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Daniel Nyorere, Ozias Nwakpu, and Leo Eromina Obogai. The first draft of the manuscript was written by Daniel Nyorere, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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