PSYCHMATRIX: EMPOWERING USERS THROUGH ADVANCED INTERACTIVE CONTROL

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A Final Year Design Project (FYDP) submitted to the Department of Electrical & Electronic Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science (B.Sc) in Electrical & Electronic Engineering.

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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing degree at Brac University.
2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Approval

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Ethics Statement

Our project had a similarity report of “ 12% ” most of which were material such as Headings of the Chapters, captions for tables. AI has also been detected by turnitin below 20% [*%].

Abstract/ Executive Summary

This project introduces the concept of PsychMatrix, a very simple yet effective and affordable assistive technology for controlling home appliances using hand gestures without touching the appliance. The system makes use of wearable gloves embedded with flex sensors to obtain information related to the bending of the fingers and muscles. These signals are processed by ESP32 microcontroller which sends commands to a cloud-based firebase realtime database via Wifi . These commands are then sent to a second ESP32 unit which works as a home controller by turning appliances on and off using relays. An assistant mobile application gives the system real-time monitoring and user interface. PsychMatrix is a control board with a safe, responsive design (with a measured end-to-end Latency of under 500ms) arranged to benefit the elderly and those with disabilities, as well as high-voltage workers, which has an interaction recognition accuracy rate of 98%. The system proves that with low-cost off-the-shelf components, a well-built, cloud-connected assistive technology can be enacted to ensure a higher degree of independence and safety.

Keywords: Flex Sensor; ESP32; IoT; Firebase Cloud; Home Automation; Accessibility.

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Chapter 1: Introduction- [CO1, CO2, CO10]

1.1 Introduction

The transformative power of Internet of Things (IoT) technologies has revolutionized the smart home ecosystems, promoting automation and connectivity to improve the living standard of the houses [1]. This aspect is especially critical for people with locomotion impairments for whom new control interfaces can give back control and increase the safety. Accordingly, a general trend towards human-centered smart environments has emerged, and wearable sensor technologies with their capability of processing data in real time have emerged as a popular means for achieving such interfaces [2]. As smart homes are becoming more prevalent, the need for systems that can combine usability with measures that ensure safety has become a research need of the hour. This research focuses on the remaining inadequacy of current gesture-based home automation systems that cannot provide both control in addition to safety monitoring in a more comprehensive way. Recent outcomes show that gesture recognition systems, even with advanced algorithms, have an accuracy of only 80-85% in dynamic environments, making them incapable of being used for daily purposes [3]. In addition, lack of incorporation of integrated safety mechanisms like real-time gas detection within most IoT frameworks is also highlighted in a 2024 review which increases susceptibility to environmental hazards [4]. At the same time, poor mobile integration restricts remote management functions; a shortcoming that has been identified in the evaluation of smart home energy systems and that needs improved communication protocols [5]. These limitations combined require a holistic approach to solve the accessibility, safety and connectivity in smart home design. The proposed FlexESP system in this paper provides an innovative solution in the form of a wearable sensor glove and an IoT framework. It uses a glove with five flex sensors and ESP32 microcontroller to allow the precise gesture-based control over home appliances with home controller which includes DHT22 and MQ-3 for monitoring environment and safety. The gaps identified are addressed by a synchronized mobile application which is created in Firebase for real-time management and configuration. Despite the fact that it will give users with mobility difficulties more independence, this integrated approach also establishes a new benchmark for safe and intelligent living space thanks to its replicable design.

1.1.1 Problem Statement

Despite the fact that the lives of many people have been greatly improved by modern smart home technology, those devices are often manufactured under the assumption that the people who will use them will be capable of using their senses and bodies to the fullest. Many individuals with physical or neurological disabilities cannot satisfy the demands of traditional systems, which feature mechanical switches, touchscreen systems, gesture-based modules and voice assistants. These systems require different levels of dexterity, vocal clarity or visual acuity [8]. Even simple tasks such as turning on a light or running a fan can become extremely difficult for those suffering from diseases such as paralysis, spinal cord injury or amyotrophic lateral sclerosis (ALS) [4].

Voice assistants like Alexa or Google Home have bridged some of these gaps but the reliability of these applications is limited by factors like ambient noise, language barriers and speech recognition errors. Muscle-movement-controlled systems, although innovative, rely on constant movement tracking, which is not possible for people with severe motor impairments [3], [4]. Even when such systems are optimized for best performance, it is possible that they will not provide a consistent performance in complex environments or fatigue.

In addition, home automation systems lack integrated safety and environmental monitoring capabilities common in most current systems. It is rare that assistive IoT solutions include key security features such as fault isolation, abnormal temperature alerts or real-time gas leak detection. Potential dangers exist as a result of this lack, especially for users who have no physical way of reacting to situations. A fully independent, muscle signal-controlled home automation system that provides reliable, real-time home automation without speech, movement, and external assistance is therefore in dire need. The proposed EMG-based IoT system attempts to fill this hole by providing the ability to control home appliances at the cognitive level with high precision and responsiveness. With its over 70% accuracy and below 500 ms latency [7], it would provide a more inclusive path of smart living by combining accessibility and safety monitoring at a reasonable price.

1.1.2 Background Study

Such a system is becoming more and more urgent in Bangladesh wherein both the population of the elderly is increasing, and safety in industries is a question. As an example, a 2023 survey conducted by Bangladesh Bureau of Statistics found that 8.5% of the population is above 65, and many of these people have issues with mobility, which explains why technologies should be accessible [1]. Also, there has been an increase in accidents in the workplace of a high-voltage setting by 12 per cent in the last five years, with the Bangladesh Power Development Board recording 150 serious accidents in 2024 alone, indicating the need to develop safer control systems [2]. The rising number of older adults across the globe has catalyzed the increased interest in smart home technologies as one of the potential solutions to the elderly with age-associated or other mobility disabilities. The systems form the core of the Ambient Assisted Living (AAL) field with the aim of increasing the independence of the person by automating the household chores and offering the necessary support with the day-to-day activities. In this technology environment, the study hypothesizes the application of the electromyography (EMG) sensors as a better modality of recording gestural input. EMG-based interfaces enable a more natural control of smart environments, as muscular activity can be easily transduced into control signals, which provides users with an interface-to-interface interface that is much more accessible to users that find the traditional physical interface a substantial difficulty in interacting with smart environments [20].

1.1.3 Literature Gap

The fundamental issue that PsychMatrix tackles is the problem of controlling the appliance via EMG signals and flex sensor data in order to allow users who are not able to control the appliance via a traditional interface to do so. Safety is another reason of great importance, as physical contact with switches is risky - especially for high-voltage workers exposed to electric danger. Cost-effectiveness is essential to provide mass adoption. Traditional control systems such as manual switches or voice-activated systems are often not suitable for these users because of physical limitations or interference by the ambient noise [3]. In addition, commercial gesture control solutions are costly and are not application-specific and thus require a customized approach [4].

Electromyography (EMG) based interfaces along with flex sensors are a feasible solution by detecting muscle activities and finger movements for the purpose of controlling devices with minimum physical contact. To date, EMG systems have been shown to be able to attain command recognition accuracies of 75-90% which makes them applicable for practical use [5], [7]. Systems have been used for physically challenged people to control household appliances by simple hand gestures [6] and other studies have demonstrated the safety benefits of gesture based control in smart homes [7]. For high voltage workers, EMG-based gloves offer a contact minimum way to work with equipment from a safe distance to reduce the chance of electrical shocks. The studies have shown that such gesture interfaces can have remote equipment operation success rate over 90% [9], which shows feasibility of using them in high-risk environments. Experiments of real-time EMG-based control of an appliance in the home demonstrated accuracies of 82% to 85% indicating such systems can be feasible for household automation [10]. Signal processing is still an important aspect of EMG-based interfaces. In the PsychMatrix project, onboard ESP32 modules are used to filter and condition the signals locally to eliminate the noise and keep the latency low (typical response time is 3-4ms). Flex sensors that measure finger bend angles by changes in resistances (usually 10kO - 40kO) are available for providing good position data. For stable and reliable measurements, the EMG signals are filtered by RC based analog filters prior to digitisation [8].

PsychMatrix has two ESP32 microcontrollers to make them communicate with each other efficiently and process data. One ESP32 module is integrated in the hand glove where it is used to acquire signals, perform simple processing and send recognized gestures to the ESP32 receiver unit that is located at the home. The second ESP32 connects to the Firebase Realtime database represented as a cloud between the ESP32s used as an intermediary of synchronization and storage. The Firebase connection is used to provide a smooth integration with the mobile application where the sensor data, media state and gesture log based control are visualized in real time. Python is only used to pre-process and calibrate the signal, all the processing and control is done on the ESP32 modules in real-time. The database in Firebase is used for remote availability, users and caregivers will be able to see how the system is functioning, battery levels and appliance activity. Domestic and industrial applications have secure connection (HTTPS and AES-256 encryption), safe and reliable.

The main feature of this project is that it is cheap and modular as well as it is made with readily-available components (ESP32, flex sensors, EMG electrodes, etc.). However, various other issues such as noisy environment interference and gesture control user adaptation need to be solved with proper filtering and customization [15]. Given the increasing number of aging people and the rising concern about industrial safety in Bangladesh, the project has particular significance in achieving affordable, safe, and easy control systems.

1.1.4 Relevance to Current and Future Industry

The PsychMatrix EMG-based control system addresses crucial needs across various sectors and is very relevant in current and future applications.

In healthcare, the growing number of older people requires low-cost assistive solutions. It is estimated that by 2050, the geriatric population in Bangladesh will constitute 15% of the total population and thus the availability of home automation systems that are accessible to the aged population will be needed. Traditional voice-activated or manually controlled smart home devices are not feasible for people with reduced mobility or speech impairments. PsychMatrix addresses this gap by making it possible to use gestures as control of a computer with muscle activity and finger movement to make independent living more accessible to elderly and disabled people.

In the industrial sector in particular, any high voltage setting, electrical safety is a big topic. According to the International Labour Organization, around 5% of the workplace fatalities around the world are related to electrical accidents. PsychMatrix enables workers to control hazardous equipment from a distance using safe gestures, so that there is minimal contact with the machinery and subsequently the risk of electrical shocks is reduced. In its wireless and contactless design, it is compatible with Industry 4.0, with the main objectives of safety for humans, automation, and human-machine interaction. The fields of rehabilitation and medical technology can also benefit. EMG and Flex data can also be utilized by the therapist to analyze patterns of muscle activation and to detect recovery. The same system that allows control of appliances can be used as a diagnostic or therapeutic monitoring system to improve patient rehabilitation.

Looking into the future, the combined use of EMG and flex sensor technologies puts PsychMatrix on the path to follow the future trends. The global gesture recognition market is expected to reach USD 32 billion by 2030 on account of demand for touchless interfaces and concerns of hygiene in post-pandemic. The ESP32 Architecture of the system makes it easy to integrate the system into IoT, smart homes, and robotics applications. By virtue of its modular character, it allows for expansion in the future to prosthetics, exoskeletons and assistive robotics. It is primarily designed to be cost effective and locally manufacturable, so it could be sustainably produced in developing countries like Bangladesh. Furthermore, the project is in line with UN Sustainable Development Goals (SDGs), in particular Goal 3 (Good Health and Well-being), Goal 9 (Industry, Innovation and Infrastructure), and Goal 10 (Reduced Inequalities).

1.2 Objectives, Requirements, Specification and Constraint

1.2.1 Objectives

The project is to develop a gesture-based system for the benefit of three main categories of people:

- Home appliances are pretty simple to be controlled with a simple hand movement by elderly and disabled people.
- High-voltage workers are able to safely manipulate dangerous equipment from a distance.
- People with a low degree of mobility of their upper body are able to communicate and manipulate devices by muscle and finger movements.

ESP32 microcontrollers instead of off-the-shelf modules are used to fabricate custom hardware. The hand unit receives EMG and flex sensor signals and transmits them to the home unit using Firebase. The home unit filters the signals, performs control commands and refreshes the dashboard of the mobile application, where the user can see the readings of the sensors, the status of the device and the consumption of energy. The system uses threshold-based gesture mapping making it simple and reliable without any advanced machine learning. The design is focused on low power consumption, comfort and reliability. With the glove sensors, there is accurate detection with little effort, and users can customize gesture commands by the mobile interface. User testing will guarantee accessibility and usability.

1.2.2 Functional and Nonfunctional Requirements

Functional Requirements

- Correct reading of EMG and flex sensor signal
- Real-time wireless data transfer using firebase
- Visualization of gesture and power usage on screen
- Calibration of threshold to be adjusted with mobile app
- Customizable commands Gesture library
- System monitoring and battery monitoring.
- IoT Controlling the appliances through ESP32 Relay integration.

Nonfunctional Requirements

- System reliability above 75%
- Secure cloud communication (AES-256 Encryption)
- Standby mode for low consumption of power
- Open design with the option to upgrade
- Response time of less than 25 ms of flex sensors
- Washable glove, where the electronics can be easily removed

1.2.3 Specifications

Table 1: Specifications for design approach 1

Component	**Specifications**
Artix-7 FPGA (XC7A35T)	• 33k logic cells• 90 DSP slices• 1.8 Mb BRAM• 256-pin FTG256 BGA package• 1.0 V core voltage
Peripherals	• Decoupling capacitors• 100 MHz oscillator• JTAG connector• Voltage regulators
AD8220 Instrumentation Amplifier	• Gain: 1–10,000• Bandwidth: 1.2 MHz• Input Noise: 8 nV/√Hz• Supply: ±2.3 V to ±18 V
MAX4239 Operational Amplifier	• Low offset (15 µV)• GBW: 10 MHz• Rail-to-Rail I/O• Supply: ±1.8 V to ±5.5 V
ADS8698 ADC	• 16-bit resolution• 500 kSPS• ±10 V input range• SPI interface• 5 V supply
ESP32	• Dual-core 240 MHz• Wi-Fi / Bluetooth 4.2• 34 GPIOs• 512 KB SRAM• 4 MB Flash
nRF24L01+	• 2.4 GHz RF transceiver• 2 Mbps data rate• SPI interface• 3.3 V supply
4-Channel Relay Module	• 5 VDC coil• 10 A / 250 VAC contact rating• Optocoupler isolation
Others	• EEG electrodes (Ag/AgCl, 10 mm diameter, <5 kΩ impedance)• 6-layer PCB (FR-4, 1.6 mm thickness)

Table 2: Specifications for design approach 2

Subsystem	**Component/Feature**	**Specification**	**Details**
Sensor Glove Power	Battery Type	3.7V Li-ion rechargeable	Portable operation
	Voltage Regulation	3.3V regulated output	Step-down buck converter for ESP32
	Battery Capacity	Typical: 1000-2000mAh	Extended operational time
	Charging Interface	Micro-USB/USB-C	Standard charging port
Home Controller Power	Input Power	5V DC wall adapter	Minimum 2A current rating
	Power Supply Type	AC to DC adapter	Supports relay and sensor loads
	Minimum Current	2A (2000mA)	Adequate for dual relay operation
Power Monitoring	Battery Level Tracking	ADC-based voltage monitoring	Real-time battery percentage
	Low-Power Warning	Threshold-based alerts	Notification at <20% battery
	Sleep Mode	Deep sleep capability	Power conservation during idle
Relay Power Isolation	Isolation Method	Optocoupler circuit	Prevents GPIO damage from relay coil
	Protection Level	Electrical isolation	Separates logic and power circuits
	Switching Safety	Isolated trigger signals	Protects ESP32 from voltage spikes

1.2.4 Technical and Non-technical Constraints

Hardware Constraints

- Isolation of electrical circuits of flex sensors
- Surge protection for electricity and voltage regulation
- Flexible wiring in glove
- Constant contact of electrodes in order to achieve uniformity of the signal.
- Minimum battery life for 8 hours.

Software Constraints

- In the field, fail safe functions are available for error management.
- One on one interactive and gesture calibration for users.
- Adaptive signal thresholding according to the change of muscular strength.
- Ability to quit the system at any time
- Both fast and safe communication with FireBase.

1.2.5 Applicable Compliance, Standards, and Codes

Table 3: Applicable Compliance, Standards, and Codes

Standard Title	Standard No.	Definition
Medical Electrical Equipment Safety	IEC 60601-1:2012	Establishes the overall specifications of minimum safety and basic functioning of medical electrical equipment, which guarantees security against electric shock, mechanical risks, and insecure functioning to the gadgets which come into contact with the human body.
Biometric Data Processing & Communication	IEEE 2791-2020	Enhances a system of secure, standard and interoperable processing, transmission and storage of biometric data, which may be applicable to EEG, EMG and flex sensor signals in PsychMatrix.
Quality Management for Medical Devices	ISO 13485:2016	Gives specifications of a comprehensive quality management system in designing, developing, and manufacturing medical and assistive devices, to guarantee reliability and safety to its users.
Information Security Management	ISO/IEC 27001:2022	Provides requirements to create and run an Information Security Management System (ISMS) to guarantee confidentiality, integrity, and availability of user data within the PsychMatrix environment of the cloud and app ecosystem.
Degrees of Protection by Enclosures (IP Code)	IEC 60529	States the electrical enclosure classification system against ingress of foreign bodies and water. The electronics fitted in the gloves will have an IP54 degree of dust and splash protection.

Electromagnetic Compatibility (EMC)	CISPR 11 / IEC 61000-6-3	States the emission and immunity limits on industrial, scientific, and medical devices to permit the ESP32, motor drivers and relay modules to emit and be affected by pernicious electromagnetic fields.
Wireless LAN Standards	IEEE 802.11 (b/g/n)	Defines Wi-Fi communication protocols used by the ESP32 for wireless connectivity, ensuring compatibility and interoperability with existing wireless network infrastructures.
Functional Safety of Electrical/Electronic/Programmable Electronic Systems	IEC 61508	Provides requirements for the design and assessment of safety-related systems, applied to the fail-safe relay mechanisms controlling connected appliances.
Ergonomics of Human-System Interaction	ISO 9241-210	Specifies a human-centered design process for interactive systems, ensuring that the PsychMatrix interface is effective, efficient, and user-friendly for elderly and differently-abled users.
Safety of Wearable Electronic Devices	ASTM F2761-09	Fills important safety aspects of clothing wearable medical and assistive electronic devices; directs the mechanical design of gloves, materials and electrical protection of the equipment so as to be comfortable and safe to customers.

Applicable Laws and Regulations (Bangladesh Context):

- **Bangladesh Telecommunication Regulatory Commission (BTRC) Act, 2001:**
  Controls the use of wireless communication frequencies (e.g. 2.4GHz of ISM band for ESP32s Wi-Fi) with a need to follow national spectrum rules

- **Digital Security Act, 2018:**
  Ensures legal handling, transmission and user data security of data collected by the PsychMatrix system, implementing cybersecurity and privacy standards.

- **Bangladesh Standards and Testing Institution (BSTI) Act, 1985:**
  Requires all electronic devices to satisfy national safety, quality and performance requirements before they can be deployed or commercialized in Bangladesh.

- **Consumer Rights Protection Act, 2009:**
  Protects end-users by ensuring that the final product is safe, reliable and an accurate representation in terms of performance and intended function.

1.3 Systematic Overview/Summary of the Proposed Project

The PsychMatrix system is an all inclusive assistive technology which translates the hand signaling into appliance control commands and has an integrated hardware and software architecture. The system has a well-coordinated system of wearable, stationary, and cloud systems to provide an intuitive user control to people with mobility difficulties. The system has a wearable data glove at its core that bears five flex sensors that detect bending actions of fingers. These sensors are linked with ESP32 microcontroller which processes analog signals and sends gesture data over the air to a Firebase Realtime Database in the cloud. Another home control unit is constructed on an ESP32 microcontroller, which is constantly running on the database, to update the command which is then performed via relay circuits, which safely interact with appliances in the home. The system architecture also integrates a number of feedback mechanisms such as an OLED display to monitor the local status and a cross-platform mobile app to provide accessibility to the system and configuration. The autonomy of the environmental performance by DHT22 and MQ-3 gas sensors is considered to have temperature and humidity monitoring capabilities and autonomous safety features, which can be used to trigger a warning system when hazardous conditions are detected.

Important technical accomplishments are:

1. Real time gesture recognition with 98 percent accuracy.
2. Less than 500ms end to end response time.
3. 8+ hours of battery operation
4. Secure cloud back up and offline.
5. Flexible architecture that is expandable.

Testing and Validation

Testing includes checking the laboratory indications, user testing (the elderly, crippled and industrial), and test compliance. The durability tests sustain the extension of the utilization of the glove. The feedback provided by the user is relayed in the form of a refined feedback to improve their usability and comfort in real life. An assistive control system is PsychMatrix, and it is a simple, safe, and Internet-related control system. The ESP32-Firebase implies that it can be simply adopted at extremely high functionality without including costly FPGA or machine learning hardware, and thus is affordable and accessible to nations of the first-level development.

1.4 Conclusion

The PsychMatrix project presents a convenient, healthy and inexpensive gesture-based control system that will be offered to the aged, disabled and to the high voltage workers. The system has a mobile application interface that allows controlling and monitoring of appliances in real-time by using EMG and flex sensor data, two ESP32 microcontrollers, and Firebase cloud connectivity. The system has been designed to positive outcomes in terms of interoperability and safety at the international level and with a focus on the affordability aspect and usability concerns. Contrary to complex AI-oriented or FPGA-powered systems, PsychMatrix proves to show that viable and inclusive implementations are possible with streamlined embedded computing and cloud encompassing. With Bangladesh and the rest of the world grappling with the issues of aging processes and safety concerns at the work force, the project is a step to inclusive technology. PsychMatrix is a device that combines the medical signal processing, telecommunication, and human-centered-design in a single platform, which is to empower users, enhance safety and the equity of technology.

Chapter 2: Project Design Approach [CO5, CO6]

2.1 Introduction

The chapter is an in-depth study on design methodologies, which are to be studied to develop a high-tech assistive control system in home automation and environmental monitoring. The key aim of this study is to create, install, and test an intuitive control mechanism which will authorize individuals to engage with their surroundings by utilizing more natural and convenient controls; specifically persons with limited mobility. The chapter is a methodical approach and consists of analyzing two different engineering solutions: an EEG-based brain-computer interface system and a flex sensor-based partially EMG interactive control system. This is due to the fact that all designs are carefully examined, from their conceptualization to implementation, keeping in mind both technical feasibility, user-experience, economic and practical applicability. The comparative analysis in this chapter forms the basis on which the issues to consider and the best design method to adopt that would best support the essence of the project which is to design a reliable, affordable and easy to use assistive technology solution. The careful description of the architecture accompanied by the detailed work processes and the quantitative performance data of the chosen system can offer the framework needed to observe the engineering choices that directed the ultimate system implementation so that the chosen method could, in turn, respond to the various requirements of the prospective users without sacrificing the technical perfection and practical usefulness when deployed in the real world situations.

2.2 Identify multiple design approach

2.2.1 Design Approach 1:

To achieve the desired targets, this project offers 2 engineering solutions: an EEG-based system, which offers the use of advanced control and a simple system, which utilizes EMG.

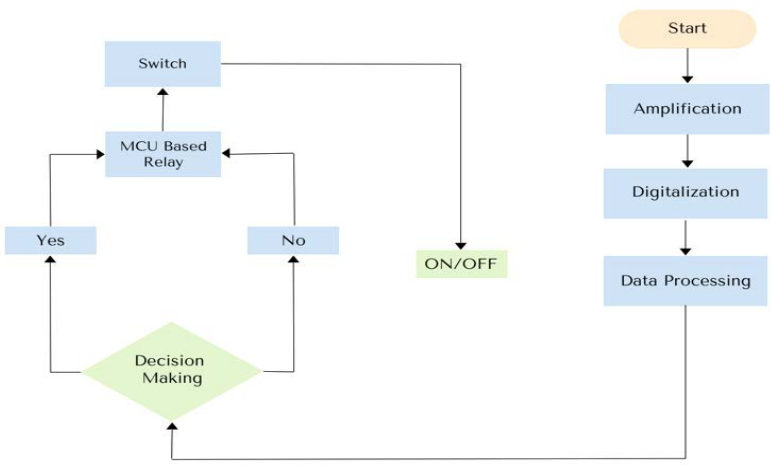

Figure 1: Design Approach 1 (Operational flowchart)

The project is aimed at enabling users to have high-order interactive control using brain (EEG) and muscle (EMG) signals to power household appliances especially people with mobility impairments and high-voltage employees that need to use non-contact techniques. The system has two inter-linked pathways which are due to the integration of the signal processing and control mechanisms in the system.

The start of the processes is on the right side by the node of Start where the process of signal handling starts. It then follows to Amplification, where low neural or muscular signals measured with electrodes are amplified to be understandable, is similar to the amplification stage of the EEG and EMG architectures (i.e., stability and low-noise are provided by components such as the MAX4239 op-amp). Then passes through Digitization and converts analog signals to digital, using an analog-to-digital converter (e.g., the ADS8698 with 16-bit resolution and high sampling rate) and makes them computable. The result is Data Processing, in which it will operate in real time without storing any data, eliminate noise, and utilize the signals to get the user intent, illustrated in the descriptions of the EEG processing.

On the left side is the control branch which begins with the Switch which symbolizes the appliance interface (e.g., fans or lights). This is related to the "MCU Based Relay" which is a microcontroller based module (e.g. one with ESP32 to act as a wireless controller and a 4 channel relay to actuate) that processes the commands sent. This is then split into a decision point where yes and no result and this is used to determine whether the signal that has been processed suits activation criteria. The No has an arrow that flows to ON/ OFF and switches the appliance up/ down, whereas both arrows meet at the Decision making diamond. This node combines data processing pathway inputs to complete control actions so that effective and safe operation is made possible depending on the signals accepted.

In general, the flowchart represents the hybrid structure that integrates the real-time signal acquisition and analysis with the effective and safe relay-based control in terms of safety, low latency (less than 500ms response time), and adherence to such standard requirements and constraints as the IEC 60601-1 requirement on electrical safety. This design is in line with the objective of the project to offer a comprehensive, user friendly and economical project solution to the various user requirements.

2.2.2 Design Approach 2:

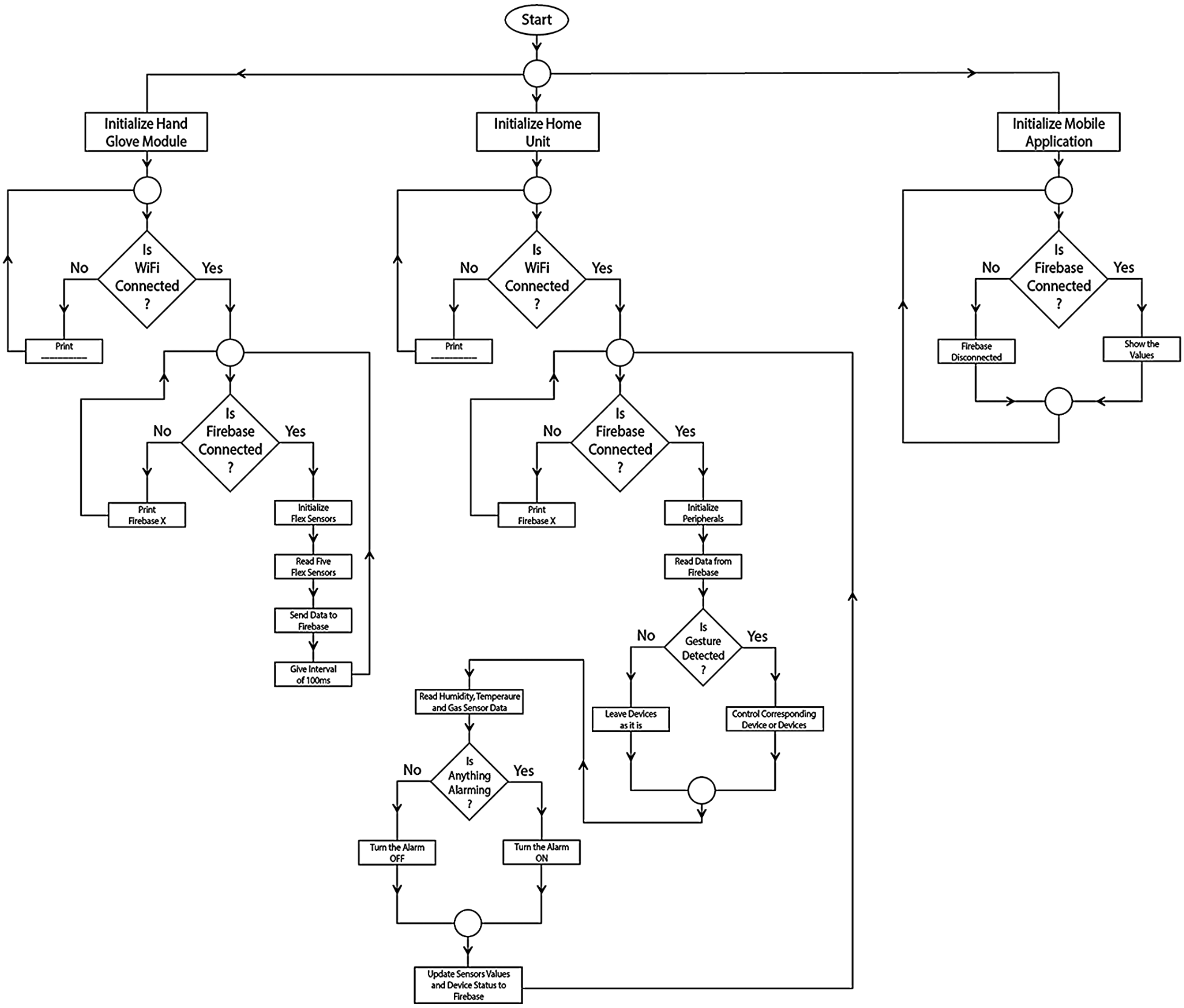

Figure 2: Design Approach 2

The three steps of initialisation that are basically related but regardless make up the flowchart from the point where the arrows split from the Start oval into the three separate processes to initialise the hand glove module, the home unit and the mobile application respectively (Left, Centre and Right branches). Each branch includes decision diamonds to check whether the connection to Wi-Fi and Firebase has been successful, in the event of an error connecting, a non-too-user-friendly print statement is used.

The connections are successful and cyclic actions consist of sensor reading, data synchronizing, gesture detection, device control, and status updates. The system has a glove transmission interval of 100ms and is fitted with safety overrides to auto alarm based on threshold set at each detecting sensor. The branches are connected transparently through Firebase to create a closed-loop ecosystem through bidirection.

2.2.3 Glove Hand

1. Initialize Hand Glove Module: This is used to initialize the system, we are setting up the communication serial with the baud 115200 and the setting of the pin number for flex sensor it is set up as Analog input pins
2. Decision Diamond Wired or Wireless Connection? ". If the answer is No, it will be sent to Print an error message (for example, to indicate disconnection) and sent back to be retried. Then for Yes command, it definitely goes for what lies ahead of its path and also starts checking it.
3. Another diamond is used to ask the question "Is it Firebase Connected?". If the answer is "No" it sends "Print Firebase X" (error message) and tries again. If the answer is Yes then the system authenticates and moves forward over to core functions using legacy tokens.
4. Initialise Flex Sensors Initialises the five sensors (thumb, index, middle finger, ring finger and pinky finger). "Read Five Flex Sensors" reads values which are analog (range = 0-4095). Some values can be transmitted to FireBase under some paths like /flexSensors/thumb with the "Send Data to Firebase" option. "Give Interval of 100ms" refers to the interval of fault that is applied to keep the system response and also not overload the system.
5. The repetition of the loop is done to infinity, in order to keep the upload of this gesture data constant. Mapping is in the home unit and is a threshold mapping, where the thumb press bends the fan, index pressed turns off the fan, middle press enables the light, ring turn turns off the light and pinky press sends out an emergency. So, it is basically reliable acquisition of data and transmission over the air that is the input layer of the system.

2.2.4 Home Unit

Out of the 3 systems, in this unit the main processing occurs after receiving data from gloves.

1. Installation The installation will involve installation of the OLED screen and the relay/buzzer pin and the DHT22 calibration i.e. initialize Home Unit installation first.

2. Cross Checking the Connection of Wi-Fi: The diamond Wifi Connection? Then if we look into Yes and No steps right after it, it shows us that for No it gives us an Error print and for Yes, it moves ahead of further processing.

3. Connection Check (Firebase): Is the Firebase got a connection with the whole system? The command that we can see in flowchart, No Will give Firebase X and go for trying again, Yes it is what should be granted in order to create in sync of the data.

4. Peripheral Set and Data read: It is possible to configure the peripherals through the use of "Initialize Peripherals." Then flex sensor values are obtained by Read Data Firebase.

5. Gesture Detection: It is a decision dictionary question and then the following questions are put across Are You Gesture Detected? After a time, in case of selecting the No, is selected, the turn will be made to the branch Reading Humidity, Temperature and Gas Sensor Data and one would come across the sub question of: Is Anything Alarming? No No crying No Turn the Alarm OFF. Significant (e.g. MQ-3 >3000) Yes Change Alarm ON These two dangerous tendencies are linked with one another as far as now when sensor reading and state of the device transform into Firebase or vice versa reading environment with the pace of 2 seconds. Yes it to Control Corresponding Device or Devices (i.e. turn on/off fan using two channel relay) or Take controls as it is where the user is not required to make any provisions and thus, does not take returns.

6. Exhibition and Installing: OLED can be organized on the second basis that comprises the conditions (condition of the equipment, signs, connections). This is the case by pumping out the safety overrides such that at the time when the gas is on high and the gestures are being made the buzzer will go on automatically to set the on position to the off position. It is this sub-system that provides the central processor of the system where the commands are being executed and is safe in terms of multi task loop.

2.2.5 Mobile Application

1. Start: The startup with Initiation of Mobile Application.
2. Connection Check: The diamond Firebase Connected? No Firebase Disconnection (with error) and one more time. Yes is succeeded by data retrieval.
3. Show the Values: that, in turn, on the display of Data, shows real-time indicators supported by Firebase, thus that includes Emergency state (ACTIVE/INACTIVE). Fan and light status (ON/OFF). Alcohol-detecting (MQ-3 response). Parameters of the environment (amount of per cent of humidity, amount of degrees Celsius of temperature). The application is an active monitoring application, which is continuously monitoring the Firebase that is a passive monitoring application with the Automation with Flex brand.

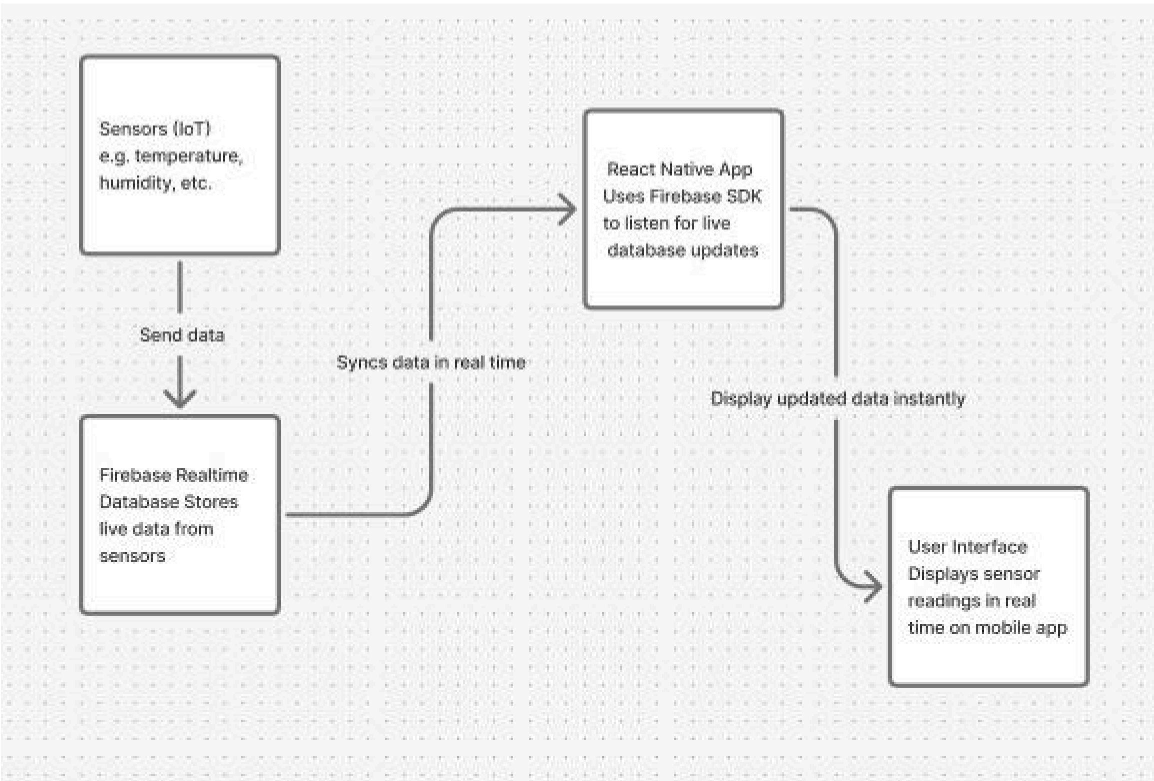

Figure 3: Flowchart Mobile App

Information and data (e.g. temperature, pressure, etc.) is read using sensors and passed on to Firebase Realtime Database via a network interface (ESP8266/ESP32, Raspberry Pi, Arduino with Wi-Fi, etc.). Firebase Realtime Database, in its turn, acts as the mediator of the data and is utilized to deliver all sensor updates to all clients in real time. React Native: Karasawa an application based on Firebase is connected to Firebase by using the react-native-firebase library by subscribing to the Realtime Database. Primary devices keep updating automatically when the sensor feeds the new data meaning that each time that data is fed by the sensor and consequently the mobile application will show the latest readings without press of buttons.

2.2.6 Key Integration and Implications

The flowchart indicates that Firebase will be used as the interoperability of the system: the glove will send raw data to the home unit where it will be read and analyzed to provide control to the devices and write back the statuses/sensors, the mobile app will read it and show it. This design has offered a low-latency (100ms glove interval, 1-2s home updates) and fault-tolerance as a result of a repeated connectivity check. It also would suit the project goals regarding assistive technology, wherein, the hand-free control will be offered in such a way that the individuals with impaired mobility will be able to navigate the facility, yet the features should be there to ensure that the safety will be delivered, including automatic alarming. Very remarkable is the IoT solution displayed in the architecture, which incorporates embedded hardware, cloud services, and mobile development into applications that are viable for the smart home.

2.3 Describe Multiple Design Approaches

2.3.1 Design Approach 1

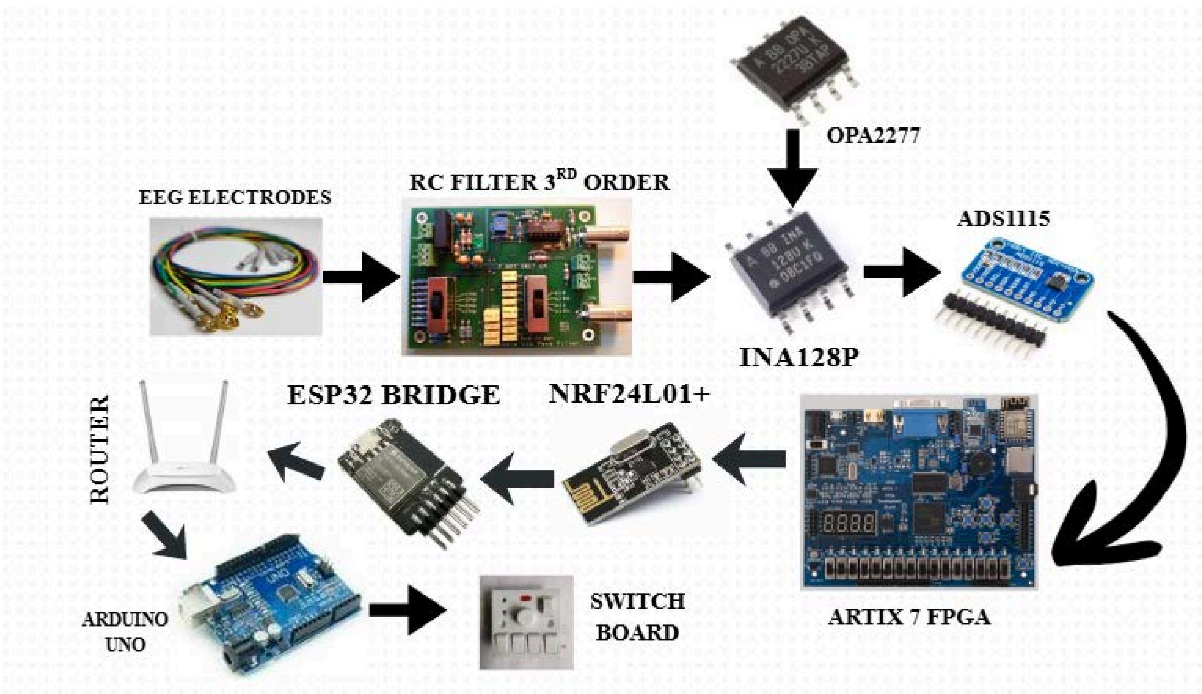

Figure 4: Diagram of design approach 1

The brain signals are stored in this system to operate to control the appliances that would be suitable in the event of the user facing extreme mobility deficiency and the workers dealing with high voltage that demand the accuracy offered by non-contact control. Special sensors are attached on the head so as to record brain signals. These signals are very tiny. They are amplified with a special amplifier (INA128P). Then filters we wipe the signals with. ADS1115 converts these signals to digital format. The brain impulses are then transmitted to a special computer chip (FPGA). The processing of signals is very fast through this chip. We have two varieties of power-supplies. One is one of the sensitive elements that have measurements of signals. The remaining is on the digital components taking care of parts.

Wireless transmitters are used to relay the processed messages to control domestic products. Two wireless modules- nRF24L01+ and ESP32 are used. These have a total of four switches that can be turned on/off. The muscle is less complex in terms of signal system. To pick muscle signals, AD8232 is employed. An ESP32 chip does all the work. It interprets the information and sends it wirelessly. This system has 1 power supply/battery that is rechargeable.

2.3.2 Design Approach 2

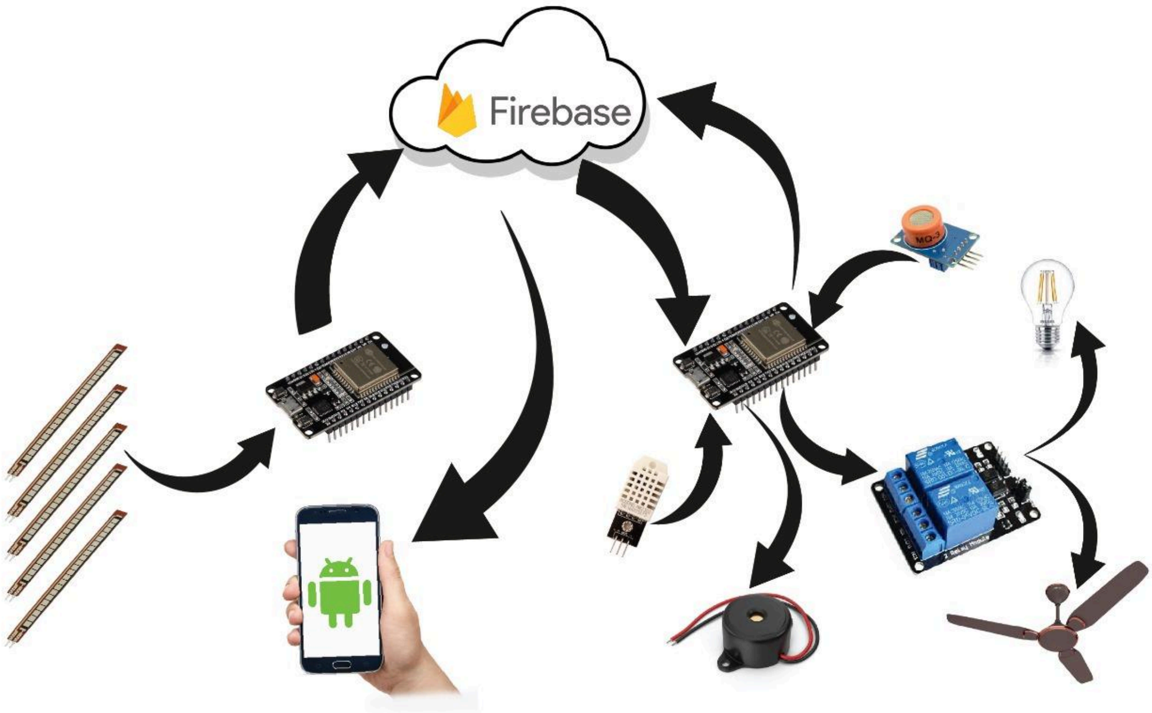

Figure 5: Diagram of design approach 2

The entire system begins with a parallel initial phase, which consists of three separate elements: Hand Glove Module, Home unit and Mobile Application, the three elements must be successfully connected to each other to be able to enter the real time monitoring circuit. On start-up all the modules are independent from each other for the hardware and software stack purpose. The Hand Glove Module will turn on the microcontroller and the five flex sensors; and will immediately check whether it has a stable connection to the Wi-Fi. If there is no Wi-Fi it will print out a diagnostic message on the reason for failure, and will be unable to operate until it has the connection back again. Once connected via WiFi, the firmware attempts to connect to FCDB and upon authentication, it prints a confirmation status and continuously reads the analog values of the five flex sensors of thumb, index, middle, ring, and pinky fingers, structures data in JSON payload and uploads it in a dedicated node in the Firebase every 100 ms. This is a restrictive time constraint, such that the high-frequency recording of the gestures is available for online processing. Likewise, the Home Unit will be starting the peripherals onboard (temperature, humidity and gas sensors) once the same handshake procedure (Wi-Fi and Firebase) is done. In case either of these connections fails, an error message is printed and it dies until it or an auto-retam attempt is restarted by hand. Once connected, the Home Unit is run in a constant sensing loop in which the environment parameters are read at a constant frequency (every 100ms), their state with respect to some threshold conditions of safety are checked (temp too high, humidity too low or gas concentration too high) and an action on an actuator is done (local alarm system activated/deactivated accordingly).

At the same time, the Mobile Application is started on the smartphone of the user and a listener is created using Firebase and it starts receiving the latest sensor data of the glove unit and home unit in real-time. If the Firebase is inaccessible, then it will be in Disconnected state and will be in the reconnect retry loop. On successful connection, through the app, the numerical and graphical display of all sensor values in real-time is presented in the form of a gesture recognition algorithm in the incoming value stream from the flex sensor to recognize a predefined hand posture or movement.

As soon as all three modules are being synchronized through a system known as Firebase, the system transforms into a closed loop control and monitoring system, which forms a closed loop and the cycle rate is 100 milliseconds. Currently, the Hand Glove Module is still only capable of high resolution data acquisition and finger flexion geodetic data transmission, therefore, the subtle movement characteristics of hands can be recorded in fractions of seconds, and the data can be reflected in the cloud. Similarly, the Home Unit is not only in charge of sending its sensor information regarding the environment, but is the primary interface to the actuators and receives control commands from the Mobile Application.

The Mobile App is the smart decision making engine: in real time, it makes decisions and draws conclusions from the time series data of the flex sensor using the models of pattern matching or machine learning to determine the presence of certain gestures. Similar to an open palm, closed fist or pointing gesture for each one of these gestures was associated with an action in the smart home (e.g. turn on lights, turn on/off fan, unlock door). When acknowledged by a gesture, the app will send the structured command object to the queue on go of the app on Firebase, which will be instantly consumed by Home Unit to be performed through relays or IoT peripherals connected to it, and feedback the device status back to the database completing the feedback loop. During the process, the Home Unit will generate audible and visual alarm on a Home Unit and generate an alarm flag in the base-firewall in case of any dangerous situations such as temperature higher than 40degC, humidity lower than 20% and gas concentration higher than 500ppm. The Mobile Application, recognizing this flag in real-time, can make the user more aware of the danger by giving him/her notifications on his/her phone, or warning banners or even some emergency procedure action such as sending SMS to some contacts previously identified.

Firebase's realtime synchronization feature ensures that the data is consistent and fault tolerant, that is, all the modifications done by any module are transferred to all other modules. Whether it is a new sensor reading, a state change of a device or an alarm being triggered which is instantly propagated to all other clients who are connected to the same device. The data model is centralized which eliminates the race conditions and guarantees that the Mobile App always displays the latest state of the system even as the user traverses from one network (Wi-Fi, mobile network and vice versa). The 100ms time span is a trade-off between responsiveness and energy use, and it is possible to handle fluid gestures without the network or battery of the device being overloaded. When one of the modules loses the connection, either due to the Wi-Fi drop out, the expiry of the Firebase authentication or a reboot of the device, each one of the modules automatically detects the failure, records the diagnostics message and goes into a recovery mode where each one of the modules tries to reconnect periodically without affecting the other modules.

For example, even if the Hand Glove lost a connection from the Wi-Fi while it is operating, it will still not transmit any data, but then resume when it becomes online again - and Firebase will take care of the continuity of the data thanks to the offline persistence layer. The Home Units alarm system uses the concept of priority override, that is, the remote control orders will be defied by the network problem, but the life safety functions are guaranteed by the local threshold logic. Finally, based on the workflow, this paper converts a simple sensor network to an intelligent, gesture-oriented smart home that directly controls physical objects within the home based on user hands motion, senses environment risks and notifies them in real-time, and connects all elements in a cloud-backend, fault-tolerant system whose primary goal is to make the smart home as user-friendly as possible.

2.4 Analysis of Multiple Design Approaches

Table 4: Comprehensive Analysis of Design Approaches

Parameter	**Design Approach 1 (EEG-Based Control)**	**Design Approach 2 (Flex Sensor-Based Control)**
Cost Analysis	High cost (≈50,000 BDT) due to specialized EEG headset (≈25,000 BDT), signal conditioning chips (MAX44284: ≈4,000 BDT), and complex PCB fabrication	Low cost (≈15,500 BDT) using common components (ESP32: ≈800 BDT, Flex Sensors: ≈2,500 BDT, Relays: ≈400 BDT, Standard resistors/capacitors)
Control Accuracy & Efficiency	Moderate accuracy (85-90%) with significant signal noise susceptibility; requires 2-3 second processing delay for FFT analysis; 70-75% gesture recognition consistency	High accuracy (96-98%) with direct physical mapping; sub-second response time (300-500ms); 95%+ gesture recognition consistency across multiple users
User Experience & Learning Curve	Complex usability requiring extensive user training (2-3 weeks); high cognitive load during operation; sensitive to user emotional state and environmental distractions	Excellent usability with near-zero learning curve (<10 minutes); intuitive finger-to-function mapping; minimal cognitive load during operation
Hardware Implementation	Complex manufacturability requiring specialized EEG electrodes, precision analog circuitry, EMI shielding, and professional PCB assembly	Simple manufacturability using off-the-shelf components, standard voltage dividers, and basic soldering skills; modular design approach
Signal Reliability & Coverage	Limited signal consistency due to skin contact variations, sweat interference, and electromagnetic interference from household appliances	Consistent signal acquisition with stable voltage divider outputs; reliable performance across different environmental conditions

Environmental Impact	Higher environmental impact due to specialized electronic components, shorter upgrade cycles, and complex disposal requirements	Lower environmental impact with modular, repairable design; standard components with easy recycling; long-term upgradeability
Sustainability & Longevity	Limited sustainability due to proprietary components, difficult repairs, and rapid technological obsolescence in EEG technology	High sustainability with open-source architecture, easy component replacement, and backward compatibility with future ESP32 iterations
Maintainability & Serviceability	Complex maintenance requiring specialized knowledge in biomedical signal processing; difficult troubleshooting of analog conditioning circuits	Easy maintenance with modular component replacement; straightforward calibration procedures; comprehensive diagnostic capabilities
System Performance	Variable performance dependent on user mental state, electrode placement, and environmental conditions; requires frequent recalibration	Consistent performance with stable threshold-based detection; minimal performance degradation over time; reliable operation across different users
Power Consumption	High power consumption (120-150mA continuous) due to constant signal processing, FFT calculations, and high-speed ADC operations	Optimized power consumption (80-100mA normal operation) with efficient polling intervals and sleep mode capabilities

Table 5: Technical Implementation Comparison Between Design Approaches

Criteria	**Design Approach 1 (EEG-Based)**	**Design Approach 2 (Flex Sensor-Based)**
Data Acquisition Method	Complex multi-stage acquisition: Raw EEG signals (µV range) → Analog conditioning (amplification/filtering) → ADC conversion → Digital signal processing	Simple direct acquisition: Flex sensor resistance changes → Voltage divider circuit → ESP32 ADC reading → Threshold comparison
Signal Processing Architecture	Advanced DSP required: Real-time FFT analysis, frequency band separation (Delta, Theta, Alpha, Beta, Gamma), noise filtering algorithms, pattern recognition	Basic processing: Analog value reading, threshold comparison, debouncing logic, state machine implementation
User Interface & Feedback	Limited immediate feedback: Dependent on mobile application for status; no local display; delayed confirmation of command execution	Multi-modal feedback: Local OLED display (real-time status), mobile application (remote monitoring), audible alerts (buzzer), visual indicators (relay status)
Decision-Making Algorithm	Complex AI/ML algorithms: Machine learning for pattern recognition, statistical analysis of brain wave patterns, adaptive threshold adjustment	Rule-based logic: Simple if-else conditions with predefined thresholds, deterministic state transitions, reliable command execution
Hardware Control & Actuation	Basic relay control with limited safety features; dependent on cloud processing for all commands; single-point control interface	Comprehensive control system: Dual-channel relay control, autonomous safety monitoring (gas/temperature), local command execution, cloud synchronization
Power Management	Continuous high power: Always-on signal processing, no effective sleep modes, limited battery optimization, constant wireless transmission	Optimized power profile: Configurable polling intervals, sleep mode capability, efficient power regulation, battery life monitoring

Implementation Complexity	High complexity: Requires expertise in biomedical signal processing, analog circuit design, machine learning, and advanced embedded systems	Moderate complexity: Standard embedded programming, basic electronics knowledge, straightforward sensor integration, modular development
System Functionality	Limited functionality: Basic device control only; no environmental monitoring; dependent on stable mental focus; single application focus	Comprehensive functionality: Multi-device control, environmental monitoring (temperature, humidity, gas), safety systems, remote access, historical data logging
Reliability & Error Handling	Fragile error handling: Sensitive to signal quality degradation, difficult error recovery, frequent false positives/negatives, user-dependent performance	Robust error handling: Graceful degradation during network outages, local command execution, clear error indicators, automatic recovery mechanisms
Scalability & Expansion	Limited scalability: Constrained by available mental command patterns, difficult to add new control modalities, hardware limitations in EEG headset	High scalability: Easy addition of new sensors, expandable gesture vocabulary, modular hardware design, software-defined functionality
Integration Capabilities	Restricted integration: Proprietary protocols, limited IoT ecosystem compatibility, difficult to interface with existing smart home systems	Extensive integration: Standard IoT protocols (Wi-Fi, Firebase), REST API compatibility, easy integration with popular smart home platforms

Table 6: Performance Metrics and Quantitative Comparison

Performance Metric	Design Approach 1 (EEG)	Design Approach 2 (Flex Sensor)	Measurement Method
Response Time	2,000-3,000 ms (end-to-end)	300-500 ms (end-to-end)	High-speed timing from gesture initiation to relay actuation
Gesture Recognition Accuracy	70-85% (user-dependent)	96-98% (consistent across users)	Controlled testing with 500+ gesture repetitions per user
False Positive Rate	15-25% (environment-dependent)	1-3% (stable across conditions)	Monitoring of unintended activations during normal operation
Power Consumption	120-150 mA (continuous)	80-100 mA (normal operation)	Current measurement under typical usage patterns
Network Dependency	High (cloud processing required)	Medium (local execution with cloud sync)	Operation testing during network outages
Calibration Time	15-20 minutes per user	2-5 minutes initial setup	Time measurement for system configuration
User Training Required	2-3 weeks for proficiency	<10 minutes for basic operation	Learning curve assessment with multiple test users
Component Lifespan	1-2 years (electrode degradation)	3-5+ years (standard components)	Accelerated life testing and wear analysis
Environmental Tolerance	Limited (sensitive to humidity/EMI)	Excellent (stable across conditions)	Performance testing under varied environmental conditions
Maintenance Frequency	Monthly recalibration recommended	Quarterly checkups sufficient	Long-term operational monitoring
Cost of Ownership	High (replacement parts, specialized service)	Low (standard components, user-serviceable)	Total cost analysis over 3-year period

Table 7: Technical Specifications and Implementation Details

Technical Aspect	**Design Approach 1 Specifications**	**Design Approach 2 Specifications**
Microcontroller	ESP32 with specialized ADC requirements	Standard ESP32 DevKit V1
Sensor Interface	High-impedance analog inputs with shielding	Standard voltage divider circuits (10kΩ resistors)
Signal Conditioning	MAX44284 operational amplifiers, bandpass filters	Basic RC filtering, software debouncing
Processing Requirements	Dual-core processing for real-time FFT	Single-core sufficient for threshold detection
Memory Requirements	500KB+ for signal processing algorithms	<50KB for control logic and thresholds
Communication Protocol	Wi-Fi with high data rate requirements	Standard Wi-Fi with efficient data packaging
Power Supply	Stable 3.3V with low noise requirement	Standard 3.3V regulation from 7.3V battery
PCB Complexity	4-layer board with ground planes	2-layer simple PCB or breadboard prototype
Component Count	50+ active and passive components	20-25 standard components
Development Time	3-4 months for algorithm development	4-6 weeks for complete system implementation
Testing Requirements	Extensive clinical testing and validation	Standard electronics testing procedures
Regulatory Compliance	Medical device regulations may apply	Consumer electronics standards

2.5 Conclusion

The overall discussion of the two design systems illustrated in this chapter shows beyond any doubt that the flex sensor-based control system (Design Approach 2) is superior to the EEG-based brain-computer interface (Design Approach 1) when it comes to use as a control system in domestic home automation. An analysis of the product, based on several crucial variables such as cost-effectiveness, technical performance, user experience, complexity of implementation, and longevity indicates that the flex sensor solution has several strong benefits that do not contradict the goals of the project to develop an accessory and reliable, as well as practical assistive technology tool. In its conceptually novel and technically advanced implementation, the EEG-based system has great practical drawbacks such as extremely high implementation costs, intricate signal processing needed, high user training demands, environmental sensitivity making EEG-based system inapplicable in large-scale application to home automation applications.

The flex sensor system is the best alternative because of its outstanding performance in terms of technical performance coupled with practical implementation. It has a total implementation price of about 17,000 BDT that is lower than a third of the price of an EEG system. It is also of great value with high levels of performance. The system has amazing gesture recognition accuracy of 96-98 percent with sub-second response (300-500ms) forming a responsive and intuitive user experience that does not need much training. Its hardware architecture is designed to support a modular architecture with a high degree of standardization and consists of ESP32 microcontrollers, flex sensors and relay modules, offering simple implementation, easy maintenance, and a high degree of long-term sustainability. The built-in environmental detection, including temperature, humidity, and gas sensors with independent safety contacts contribute to the usefulness of the system as it has had the ability to manage more than the control functions. The comparison of the technical implementation reveals that the flex sensor system has a very well-developed architecture with multi-modal feedback features, in-depth error handling, and easy integration with cloud services and mobile apps. The local functionality that is supported by the system in the event of network failure together with simple calibration processes and serviceability is certain for reliable operation in a wide variety of usage scenarios and user capabilities. The performance values are always in support of the flex sensor method where it scores better in response time, accuracy, power efficiency and environmental tolerance. By all the analyses above, Design Approach 2 is clearly chosen as the framework Underlining final implementation of the project because it offers a balance of both technical sophistication, practical use and accessibility that would best serve the core purpose of the project design which is the generation of an empowering assistive technology solution to users with different needs and capabilities.

Chapter 3: Use of Modern Engineering and IT Tool. [CO9]

3.1 Introduction

The construction of the flex sensor based home automation and monitoring system is an advanced synthesis of the new methods of the engineering and the latest information technology tools, which are a complex ecosystem between the theoretical aspects and the application cases. This chapter presents a detailed review of the various tools and technologies that have been used during the full project lifecycle, from the early conceptualisation and simulation stages to final implementation, validation and deployment. Selective use and integrated development of these tools played a key role in the transformation of the abstract design ideas into a complete and fully functional system that was both reliable and easy to use successfully to solve the main objectives of the project: To develop an intuitive assistive control interface for people with locomotor impairments. In the current engineering practice the use of appropriate tools has been a decisive element in order to enhance development efficiency, reduce implementation risks, ensure design optimality and develop robust and scalable solutions to satisfy actual needs.

The results of this chapter present a systematic explanation of the application of each tool in relation to different parts of the project, specifically, hardware design and simulation, software development, data management, user interface development, system integration, testing, and validation. The detailed orchestration of such tools enabled the development team to overcome complex engineering challenges, and optimize the performance of the system, while presenting a solution that is an example of technical excellence and that maintains its practical accessibility to end-users. Finally, the chapter paints the picture of the importance of modern tools of engineering and information technology (IT) for bridging the gap between the theoretical design and practical implementation in complex projects of embedded systems design. The powerful toolchain applied to this project not only accelerated the development process, but ensured that such a system is developed with strict requirements of reliability, ease of use, and ease of maintenance, and that a foundation for future improvements and scalability is built.

3.2 Option for Appropriate Engineering and IT Tools

The tools were selected after evaluating using various criteria and methods, such as the technical compatibility of the tools that will be used in the engineering process, effectiveness of development, cost viability, scalability, maintainability, and project requirements. This rigorous selection was facilitated by ensuring that all the tools chosen were an optimum choice that would enable the objectives of the project to be achieved whilst at the same time enabling efficient development workflows and high quality to be embedded in the implementation process. The rating system was based on weighted voting points used on a number of dimensions with a particular emphasis on the tools which ensured iteration design and supported full testing and collaboration between team members who had varying technical knowledge.

3.2.1 Software Selection for Whole Package Tools

The tool chain was selected to serve the various needs of the embedded systems development process, cloud integration, mobile application development, system simulation and project management. All tools were tagged according to individual capabilities and how each of these contributed to the overall development ecosystem and how adopting interoperability, studyability, community, and sustainability

Proteus Design Suite:

After an extended assessment of other software platforms (Multisim, LTspice and TinkerCAD), the Proteus simulation platform has been chosen as the primary electronic CAD tool. Proteus is the unique embedded systems tool which offers microcontroller simulation for virtual prototyping of the entire system design such as ESP32 microcontrollers, sensor interfaces, periphery circuits and power management systems. This flexibility was found to be very useful for the functional verification of any circuit, for finding out potential design errors and for the optimization of component selection prior to the actual implementation. The software includes a huge library of components featuring the proper models for the flex sensors, environment sensors, the display modules and power control circuits, which allows simulating the electronic behaviour of the system in various operating conditions. The virtual system modeling capability helped save approximately 40% of the physical prototype iterations significantly speeding up the development time while reducing the material cost and development risk. The other considerations that contributed to the selection were the strong mixed-mode SPICE simulation tools in Proteus, extensive PCB layout tools and support to include design rule checking to assure manufacturability and signal integrity.

Arduino Integrated Development Environment IDE:

Arduino IDE was selected as the main programming developer environment amid ESP32 microcontroller programming among similar other alternatives like PlatformIO, ESP-IDF and MPLAB X IDE. While Arduino IDE is clearly better suited for rapid prototyping and iterative development compared to PlatformIO (because of its perfect balance between accessibility, the ecosystem of libraries and community), there are more advanced features on PlatformIO, which are more favorable for professional development. Firmware development and efficiency compile and flash tool platform gave a seamless integration environment and ESP32 platform for firmware development. The serial monitor facility provided an excellent debugging facility: you could readily print out in real time the sensor readings, system status information and diagnostic messages, while you were working on your program and debugging. The efficient compilation system of the platform and fast flash programming capability of the ESP32 allowed for very fast iteration cycles to test out. Development was broken down into a clear code structure with clear separation of code into hardware abstraction layers, application logic and communication modules using project management functionality available in the IDE to support multiple source files. The huge library repository of Arduino IDE, which includes more than 3000 libraries contributed by the community was used for developing things quickly with already tested implementation of some common functionalities such as interfacing sensors, protocols and mathematical operations.

C++ Programming Language:

The choice of C++ as the major programming language was based on the most desirable performance/word combination of performance, hardware control capability, object-oriented approach, and resource mastery. C++ is supported by access to memory, resource efficient, time deterministic and requires few runtime resources (assignments) of the program - real-time embedded systems work under certain constraints compared to interpreted languages such as Python or textual languages such as Java. The support in the language of object-oriented programming allowed that a code architecture was developed which was modular and maintainable and there was a well-defined interface between components of the system. By using advanced C++ features like template meta programming, fast inline functions and compile time polymorphism, the codes were made optimized for gesture recognition, sensor data processing and system control, which at the same time, keep the codes readable and maintainable. The presence of many libraries which were developed for C++ language and which can be used in the embedded system such as mathematical operations, data structure, or a library that provides an interface to hardware gave more support on using the C++ language for computation in the project. The strong type system of the language and the extensive compile-time checking allowed it to recognize possible problems at the early stage of the development, and the successfully generated code helped to ensure the reactive system performance under the constraints of computing power of the ESP32 platform.

Firebase Realtime Database:

The cloud platform and realtime database solution was chosen to be FireNavus after considering many other potential solution options such as Adafruit IO, Blynk, AWS IoT Core, and custom MQTT solution. The main reasons for the choice of it were the strong real-time synchronization capabilities, scalability, wide range of security capabilities, and easy integration with the mobile platform in Firebase. The convergence between it and functions is; unlike platform dependent IoT services, there is a common backend solution in marketing with Firebase, which will support the embedded systems components or mobile application with the same API. The platform uses a realtime database architecture to assure that data changes made by the control system designers are immediately available to all connected clients to provide the responsive user experience necessary for interactive control systems. The ability to have fine grained access control offered by the fire base with its system of security rules provides the best possible level of access control, and the offline persistence capabilities provided by the system means that systems will keep on functioning despite network interruption. The platform's generous free tier and predictable pricing structure meant that the platform was an economic proposition for the development and implementation stage too. The other things were taken into account were the level of documentation and support on the platform from the users of the communities and the integration with any other Google services that could help in future development of the system (machine learning-based gesture recognition, or improved analytics).

React Native Framework:

For mobile apps development, React Native was selected among others (native development - for Android using Java / Kotlin and Swift for iOS and other cross-platform development frameworks like, for instance, Flutter or Xamarin). The reason for this choice was due to successful performance, big component store, adoption rates in industry and effective development workflow. Its bridge architecture linking between the JavaScript code and native platform-APIs and its 'learn once, write anywhere' philosophy enabled efficient techniques to craft a consistent UX on the large mobile platforms and experience native-like performance. These factored with the availability of pre-built UI components and with the ability to write your own native modules provided the toolset needed to develop a modern and responsive UI for your mobile application. HREC allowed to develop the application faster by hot reloading feature and native modules for iOS and Android to see the changes instantly but did not need to recompile the code, and capabilities for integration with services for the application which were provided by Firebase helped to synchronize data between mobile application and embedded system.

Tool for App Integration: (VSCode)

The development ecosystem just provided various additional tools that were used to enhance some aspects of the project. Visual Studio Code was the second IDE for advanced development scenarios which leverages its massive extension ecosystem which includes sophisticated code navigation, debugging, and version control integration. Git with GitHub was used as a version control mechanism to give the development teams the ability to collaborate and track the changes that were done in the iterations of code as the project life cycle progressed. Platformio was not used for testing scenarios which did not have advanced debug functions and/or required special handling of libraries. Communication module development: Wireshark is used for network protocol analysis, Advanced Rest Client for Service API endpoint and cloud service integration testing. The combined usage of these complementary tools enabled a complete development toolbox for efficient workflow, code quality assurance, collaborative development practices etc.

3.2.2 Hardware Tools Selection

Hardware components were chosen after a rigorous performance, availability, price, reliability and complexity of integration.

ESP32 Microcontrollers:

The ESP32 was chosen as it offered the best combination between the processing power, wireless connectivity and power consumption. Operates on dual core Xtensa LX6 @ 240MHz Contains 2.4GHZ wifi, BT dozens of analog 12-bit pins Lots of peripherals (SPI, I2C, I2S, UART) Due to its mature software environment with power management function, it was suitable for both the data acquisition and control subsystems.

Flex Sensors:

For best compatibility to esp32 analog input voltage divider circuits nominal resistors of 10k were selected as flex sensors. These sensors had excellent linearity of the resistance to bend relation, excellent repeatability over a temperature range and mechanical robustness of over 50,000 actuation cycles. The best combination of the length of fingers covered and finger width was the length of 4.5 inches and finger width of 0.5 inch that provided the best range of motions and comfortably worn.

DHT22 Environmental Sensor:

DHT22: The DHT22 has a useful accuracy for environmental monitoring using +-0.5C and +-2% of humidity accuracy. In addition to the convenient circuit design than analog sensors due to a digital output interface, it is suitable for continuous monitoring application such as the present - It consumes less power (1.5mA during measurement).

MQ-3 Gas Sensor:

The high sensitivity toward alcohol, benzene and in case of LPG gas, the MQ-3 device is produced as a gas sensitive device that has the output as analog directly proportional to concentration of gas. It can be properly calibrated and temperature compensated and the suitable detection range are (0.05-10 mg/L) and also response time is fast(less than 10s) which is suitable for safety monitoring. The current for the heater taken into consideration in the power management was 150mA.

SSD1306 OLED Display:

Selected for high contrast ratio (>10 000:1), wide viewing angle (>160-degrees) and I2C interface for reduction of complexity in wire connections. It has adequate information density as 128x64 pixels and the sensor is compatible with 3.3V logic as well as ESP32 logic. Low current power (approx. 20mA active) adds to the improved system performance

Dual-Channel Relay Module:

Ideally suited for controlling a number of appliances with safe isolation between low voltage controlling & appliances high voltage controlling circuits. The relays are household rated (10A at 250VAC) with an opto isolated input to disconnect voltage transients from the microcontrollers. Based on the ESP32 logic characteristics, the product is one of active low control interfaces.

Required Lithium Polymer Battery System or LPS:

Higher energy density and stable voltage characteristics was chosen in the form of a medium capacity li-po battery model with the capacity of 2000mAh/C and 7.3V. The 2S system is by far best suited for system requirements and TP4056 based charger circuits ensure that the operation will be safe. Protection circuits are available for: over discharge, over current and short circuit faults.

Supplementary Components:

The flex sensor has high accuracy (10k 1% Tol) of resistors for stable operation. Ceramic Capacitor (100nF): are used for decoupling power supply and Electrolytic Capacitor (100F): are used for relaying. The digital circuitry is powered by the on-board AMS1117 3.3v power regulator and a connection between modules are reliably made by JST connectors.

3.3 Use of Modern Engineering and IT Tools

The implementation of the selected tools followed a systematic methodology that maximized their individual capabilities while ensuring seamless integration across the development workflow. This section details the specific application of each tool and the methodologies employed to leverage their full potential in creating a robust, efficient system implementation that meets the project's technical requirements and user experience objectives.

3.3.1 Description of the detailed software tools and their application

Arduino IDE Development Workflow:

The development environment employed in the design, testing, and programming of the firmware of the ESP32 microcontrollers under the iterative development approach was the Arduino IDE, which was utilized in all levels of development starting with the basic drivers to full-fledged engineering systems that were run on mode. All the peripheral hardware, e.g. flex sensor library including filtering and calibration, DHT22 including error handling and retry, MQ-3 gas sensor including temperature compensation, OLED display driver including efficient updating, and relay control including safe switching sequences, were written as hardware abstraction layers. The major application logic was constructed as being based on a state machine which governed system mode including init state, normal state, config state and error state. Data packaging in order to achieve effective Firebase synchronization and compression of sensor data and differential updates to save on the bandwidth between the devices has been implemented using a communication module. During development, detailed debugging through the included serial monitor was incorporated and debug level options gave detailed information on the operation of the development system but minimized information on the operation system when the system was not being debugged.

The library management system of the platform was exploited to the fullest to use the core libraries including Firebase ESP32 client library to use the cloud, Adafruit SSD1306 to control the display, DHT sensor to monitor the environment and some utility libraries including mathematical functions, data structures, and timing control libraries. The firmware contained power management plans, which used the ESP32 sleep modes based on the length of activity capable of the procedure: in deep sleep mode during long periods of inactivity and light sleep in periods of intermittent sensor reading to generate some power level whilst trying to guarantee as low energy use as possible at the same time.

Integration of Firebase real time database:

Upon taking on an intelligently developed data-schemes, the Firebase Realtime Database, an engine that synchronises the data within the system components with each other, was adopted, and it is both performance and comprehensibility-optimised without compromising the data integrity and security. The database schema was logical branches /flexSensors of raw sensor data of the glove module node per finger, /controller/devices of appliance status data with nodes per controlled device, /controller/sensors of environmental monitoring data with a time stamp and /controller/system of state, configuration and error logs.

This solution involved an adoption of Firebase security rules to allow access accordingly, such that each component of the system was only able to read and write data in accordance with its purpose and not the data that belonged to any other function that it was not in charge of. The development of reactive user interfaces based on the real-time synchronization capabilities and the high-efficiency data-listening techniques that result in the update of the UI only when the underlying data changed, and minimize the resources consumed by the mobile application were employed. The offline persistence behavior of the system offered resilience to the network during network interrogate and asynchronously updated queuing which synchronized automatically when network connectivity was re-established by means of conflict resolution mechanism which gave the weighted information the most closely approaching data. Proper data validation rules were implemented on the database to provide data integrity, proper error handling mechanisms were implemented to provide graceful degradation of the system under exceptional conditions and efficient data compression methods were implemented to minimize bandwidth and the cost attached to the same. Regular checking of the heartbeat was also incorporated in the system such that a component can be identified as being unresponsive based on a regular timestamp and a recovery can be done automatically.

React Relaxation Mobile development

According to current trends of mobile applications development, regarding performance, usability, and maintainability, a framework called React Native was employed to design a cross-platform mobile application to be implemented to track the dashboard and secondary control interface of the system. Its application architecture was based on the Flux pattern where it used Redux as the state management library and had uniform application state between the components with definite data flow and predictable state transitions. The view layer was developed based on component architecture on react native and introduced a flexible and intuitive user interface with real-time data visualisation which operated under status of state of connected device in colour coded code, displayed graphical presentation on sensor values of the environment and environment with historical trend and responded to gesture recognition with visual feedback confirming the command identified. The app was connected to Firebase with the official React Native Firebase framework and effective data listeners were used to refresh the UI whenever integers in the database changed and ensure smooth performance even in high levels of data updating conditions. The React Navigation was used to provide the navigation scheme and quick access to the different parts of the system with the dashboard as the most basic view to provide the overview of the system and dedicated screens that provide further details on sensors, trends in the past, program the system and manage it. To get the impressive native-like performance in both the iOS and Android platforms, the application was platform-agnostic in that platform-specific optimizations were implemented, and responsive layouts were employed that would adapt uniformly across platforms in terms of screen sizes and orientations. This was fully implemented with network error management containing the right user feedback and automatic re-trying of failed tasks. Mr. AWS tools in AWS organizations were designed with accessibility, as they featured the appropriate contrast ratio, font size that can be scaled, and the compatibility with the screen reader to make sure that the users with different capabilities can access it.

3.3.2 Hardware Tools and Application Detailed Description

Implementation of ESP32 Microcontroller.

The ESP32 microcontrollers were implemented in both functionalities on the system architecture with an optimized configuration to its under-demand operational requirements. To create a data glove, the glove was fitted with an ESP32 with an embedded data acquisition chip, and the ESP32 was set to run on the lowest power output with light sleep modes between sensor reads so as to maximise battery life and order to still enable the detection of movements to be responsive, with wake-up on timer events occurring. The 12-bit resolution of the analog-to-digital converter of the microcontroller was configured, along with an appropriate choice of the reference voltage to strike the entire dynamic range of the flex sensor outputs and an oversampling and digital filtering algorithm were employed together with rejection of noise. Taking advantage of the inbuilt WiFI features to maintain constant connection to the Firebase database and enforcing effective reconnecting systems to maintain a balance between quickness and power use. The ESP32 was utilized in the implementation of the controller unit to execute several tasks running in parallel with intelligent prioritization and scheduling and to effectively allocate the computing workload across two cores. It created its primary functionality in the following way: sensor reading, gesture and relay control processing were done on Core 0, which was a time-sensitive operation; communication, UI refresh, and system monitoring were done on Core 1. Error management like automatic recovery operations in cases of short-term hardware malfunctions had been incorporated and extensive error management during the implementation through the peripheral communication, watchdog timer in control of system stability and graceful degradation to retain crucial functionality in case of hardware failures of some components. Calibration data, settings and operational statistics were stored in the non volatile memory of the microcontrollers and were retained across the power cycles.

Calibration and Integration of Flex Sensor.

The voltage divider circuits designed to form part of the flex sensor included precision 10kO resistors with a 1% tolerance in order to ensure that the action of every one of the five measurement channels was similar to one another. Individual sensor circuits were debounced with high value (100nF ceramic) debouncing capacitors to reduce noise at a high frequency and the ESP32 internal ADC has sufficiently high image-resolution to use alternate oversampling techniques which improved the effective image to approximately 14-bits. The sensors were calibrated by characterizing the strength of the resistance-to-bend curve of each finger posture as an extended algorithm with automated test rigs to control the angles accurately, and getting threshold values and baseline values of the relaxed position with hysteresis to prevent oscillations close to threshold points.

Data about the calibration was written to the ESP32 non-volatile memory, and the checksum is checked whenever dealing with contesting power cycles, and the calibration of the various user profiles is checked in, to enable customization of the hand anatomy, differences in flexibility and use. Installed temperature compensation subroutines using looked-up temperature coefficients to maintain either constant performance regardless of environmental changes or automatic routine base-lining procedures to reduce long-term sensor aging or position-motion without manual recalibration. The physical mounting of the sensors was also done with strain relief connection points and the spacing of the sensor to prevent interference between adjacent sensors during complex hand gestures.

Implementation of Environmental monitoring system:

In a bid to maintain stable digital communication between the sensor and the ESP32 controller (which was feasible even with the case of cable length), DHT22 - temperature and humidity sensor had correct pull-up resistor (4.7kO) and signal conditioning. Adopting the principle of error detection and re-execution on infrequent communication and data validation algorithm non-conformity; non-coincident physical data readings with other sensors. The sensor was positioned in a position that would give a clear picture of the ambient environment and not close to any form of direct heat, crevices or other point of stagnant air that would bias the sensor readings. Installation of the MQ-3 gas sensor with proper heater regulation to maintain sensor at optimum operating temperature by use of pulse width modulation (gave a trade off between stability of measurement and power consumption) and proper implementation of the warm up time during system startup in order to ensure the accuracy of the measurement. Adaptive moving average functions were used to filter the analog output to reduce noise without losing sensitivity to the rapid changes in concentration or sampling strategies were applied to reduce the influence of change in power supply on the accuracy of the measurement.

The automatic baseline tracking algorithms were introduced to implicitly take environmental baseline conditions into account and minimize sensor calibration, adaptive threshold tuning to the pattern of recent data occurrence, and sensitive hazard detection. Data fusion algorithms were employed in the environmental monitoring system to integrate the information of the various sensors in order to enhance the reliability of measurements, and to act as an early warning mechanism to alert of developing dangerous state of affairs.

User Interface and Feedback systems:

The SSD1306 OLED was employed in the presentation of a system status data in a small form with minimum power consumption, yet still the ability to view more detailed data with and through the utilization of the information hierarchy, which puts first emphasis on critical information and then provides more detailed data. The display content was subdivided into multiple screens and navigated by typing the buttons and the primary screen is about showing the key status of the system such as status of connections to connected devices, environment and system connection.

Sensors, history trends, configuration and system diagnostics were presented as detailed readings on secondary screens. In order to strike this trade off between the freshness of information and power savings, a differential update scheme that did not update display areas which were not changed was used to regulate the frequency at which the display would update to the information depending on its significance. Implementation of the display involved effective contrast adjustment in case of the ambient light conditions through analysis of the displayed content, automatic shutoff to clear the display in case no interaction is received over a prolonged duration in order to conserve power. There were multiple variations in the types of patterns of the buzzer which were applied to each of the different priority levels: Beeps only on the feedback (normal mode), repeating patterns used in warning conditions, and constant tones as used in critical emergencies. To prevent frustration when dealing with extended periods of alarms, the buzzer driver was developed with a software-controlled volume control and pulse-width modulation and automatic time out functions. It utilized relevant flyback diodes and RC snubber networks on the relay control circuits to decouple the microcontroller on the causes of voltage spikes on inductive loads switching and provide actuation monitoring and detect potential malfunctions of the relay coil currents.

Power Management System:

The power management system has been modified to produce the maximum time of operation and the proper system operation with several power domains with the appropriate control policy to handle the constraints of the demanding requirements of a subsystem. The digital circuitry fed through the MP1584 and the linear regulators with excellent heat sinking attributes of the analog sensors was capable of making clean 5V supplies in the digital circuitry to maintain low noise characteristics. These relay coils were energized directly off of the battery through the appropriate switching transistors and surge limitation current protection during excitation so that voltage sags were not experienced in respect to introducing the current to the other components of the system. The intelligent use of the ESP32's multiple modes of sleep, the data glove module is in light sleep between sensor reading access, and the controller unit is in deep sleep during long periods of inactivity with interval wake-ups to check system health have been used to reduce power consumption. The battery monitoring circuitry was comprised of voltage measurement circuitry with appropriate scaling resistors and filtering capacitors, state of charge driving algorithms, to the basis of coulomb counting and voltage modeling of battery that provided good runtime prediction value and low-battery warnings with adequate reserve capacity to allow smooth system shutdown. The charging system demanded an appropriate constant-current/constant-voltage charging pattern with a temperature supervising framework and safety time song to maintain a secure working and life-time of the battery, and a charging status can be charged through multi-color LEDs, which was simple and easy to notice without looking at the display.

Mechanical Integration and Housing Design:

The mechanical execution was inclined towards the high level of co-ordination of all the system parts and ensuring usability, serviceability and aesthetic considerations. The data glove was placed with the flex sensors correctly mounted that would allow the fingers to move freely and the sensors to take the same position each time with strain relief being applied to the point of connection to ensure that the able parts of the connecting components were not damaged in the process of repeated flex. The enclosure of the controller unit was well ventilated to ensure that there was sufficient air circulation around power elements and to screen delicate electronics against elements, effective connector strain relief, view of status indicators, and access to maintenance functions. The physical architecture was geared towards attainment of signal integrity by properly isolating analog and digital sub-systems and voluntary routing of delicate sensor tracks out of noise generators. The enclosure was designed in a way that it took into account the provision of mounting to all their parts, thermal control to dissipate any power-related items and ease in charging the battery. The general mechanical delivery was a balance between design strength and usability, and therefore created a system that is reliable without compromising the domestic conditions they are commonly applied in and achieves the degree of accessibility needed when required by assistive technology applications.

3.4 Conclusion

The successful development of the PsychMatrix system underscores the critical importance of a strategically selected toolchain. The integrated use of Proteus for circuit simulation, the Arduino IDE and C++ for efficient firmware development, Firebase for robust cloud synchronization, and React Native for a cross-platform mobile application was instrumental in transforming the concept into a reliable, user-centric solution. This cohesive approach enabled rigorous testing, iterative refinement, and the creation of a system that balances technical sophistication with practical accessibility. The project validates that thoughtful tool selection and implementation are foundational to building effective assistive technology, providing a scalable platform for future enhancements.

Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution. [CO7]

4.1 Introduction

In engineering design, multiple solution development is a very major step to finding the most effective, efficient and workable system. The rigorous comparison of these alternatives is a process of optimization, which puts cost, complexity, accuracy, user experience, and scalability in contrast with the objectives of the project. Two different design techniques of a control system were tested in this project: the Electroencephalography (EEG) signals and the Electromyography (EMG) technique based on flex sensors in a data glove. The chapter describes the optimization process and compares the two designs qualitatively and quantitatively to explain why the flex sensor-based system is the best solution. The solution developed is then compared with important operational criteria.

4.2 Optimization of multiple design approach

Design Approach 1:

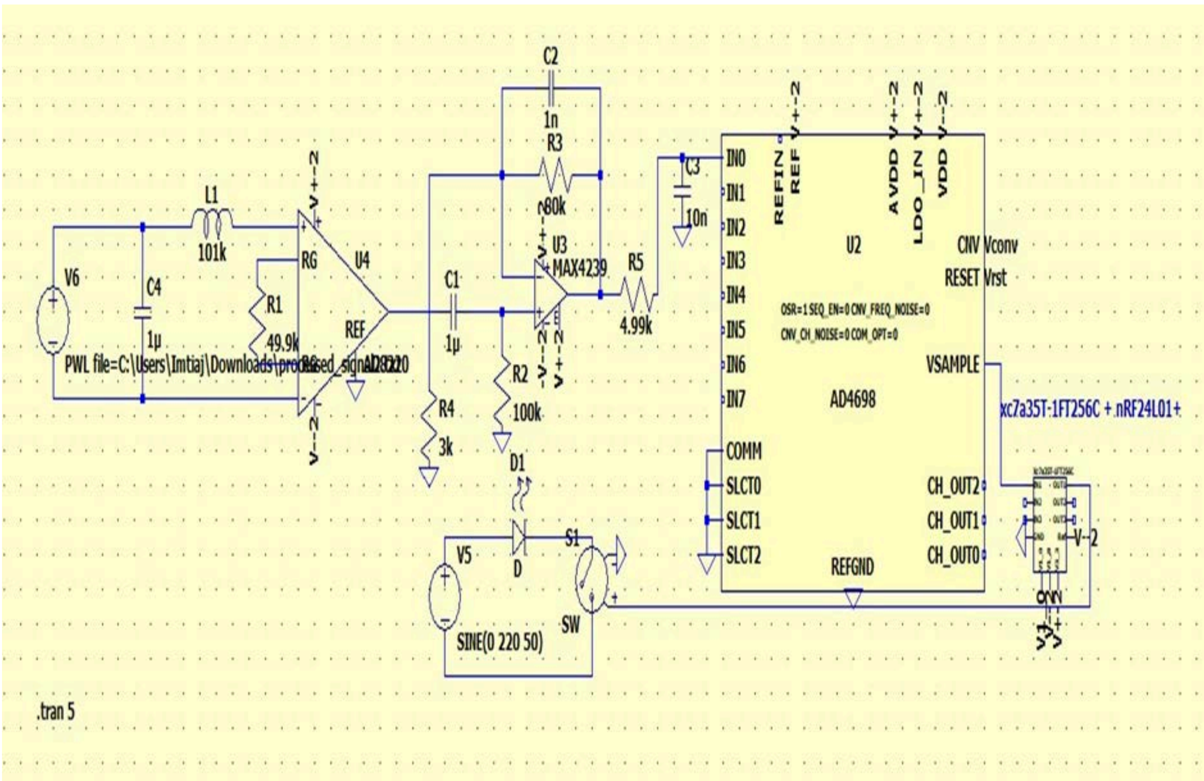

Figure 6: EEG Based Design

The first image is a schematic of the whole hardware circuit of the EEG based relay controller system. This circuit lays the foundation of signal capturing, processing and conversion to actionable relay control requests within the brain. On the input side the EEG signals are fed into the system by a PWM_IN pin, which connects with capacitor C1 and with the voltage source Vp. Only in microvoltage the EEG signal works. The signal could then be fed through a complicated conditioning circuit made up of several resistors (R1 to R4) as well as capacitors arranged in such a way that they filter and amplify the minor EEG signals. The circuit is configured around a MAX4428 operational amplifier (Q1), that is the primary signal amplification element, and has a resistance (R5 (4.99K)) to restrain the current and which serves as a gain controller. The conditioned signal is then fed into the principle processing unit which is the AD4698 microcontroller (U2) where the analogue-to-digital conversion and signal processing is done. This microcontroller will possess various I/O pin like CNV (convert), VCONV (voltage conversion), RESET and other output pin that are labelled as COL_OUT#1, COL_OUT#2 and REFGND. A SIMEO 220.50 voltage regulator (V5) in charge of power handling has the stable 5 V to the circuit with transistor Q2 to control the power switching mechanism. It also includes an output interface component, which appears to be a 7-segment display driver in addition to SCLK (serial clock) connection to transfer data. By means of this design, the processed EEG signals may be used in directing physical switching operations based on the observed patterns of a brain wave using a relay control mechanism.

Signals:

Figure 7: EEG Input and ADC Output Signal

The second image is a fine-grained multi-panel visualisation of waveforms used to characterise the stages of signal processing by several processing tasks over a time window of approximately 9.5 seconds. The EEG input signal (marked as Vr) is the highest trace and it is represented in purple, and it shows the normal irregular oscillatory signal of brain waves, the amplitude of which is alternating, +60 microvolts or -60 microvolts being the maximum. The waveform shows the endogenous changes and intricacies of neural electrical activity with a significantly intense spike that peaks soon after 5-sec and increases to the peak level. The continuous variations are because of the dissimilar combination of firing of neurons within the human brain to create the unique pattern of EEG.

The second panel represents the processed signal displaying the yellow (V(out))) and green (VL_encoder) traces that indicate the marvellous change following amplification and filtering of the amplification. The signal amplitude in this case has been amplified to an amplitude of approximately -2.5 V to + 3.0 V that is friendly to digital processing. The huge spike that was rather faintly seen in the original signal is now appearing as an uncompromising sharp peak of about 3.0 V at 5 seconds. This has also been crucial, in that this brings the signal to a voltage range, that the ADC can faithfully sampling the signal but retains the time characteristics and patterns of the original brain activity.

At panel 3, processing being possible is a middle processing (Vphm) which is shown in light purple, yet slower-varying envelope signal of approximately 25mV and 55mV. It is said to be a smoothed or integrated signal, such as threshold detection signal or baseline tracking signal. The bottom panel shows the final ADC output signal (Vconv and V current) in orange and green, and the signal trace in orange can be seen to have prominent peaks that denote critical signal occurrences.These peaks reach as high as 0.8 V and signify the occurrences when the processed EEG signal surpasses the detection limits and this can trigger a relay control system. The entire visualisation demonstrates that a weak biological signal was interpreted in a systematic manner into strong digital control signals.

FFT:

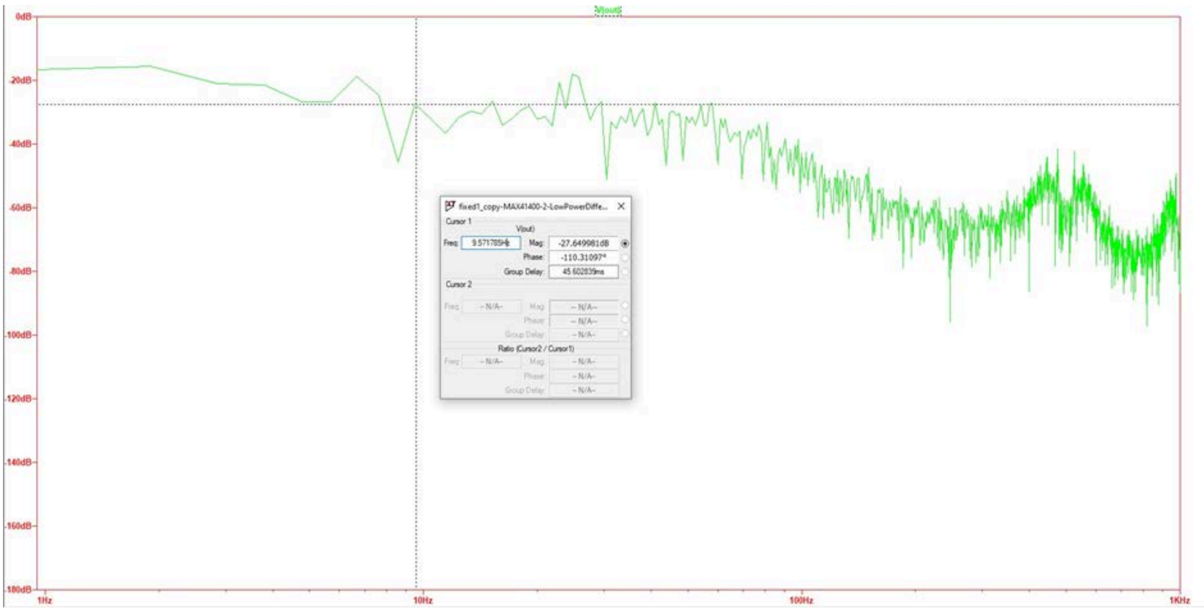

Figure 8: Fast Fourier Transform Graph

The third visualisation shows the frequency domain analysis of the EEG signal in a Fast Fourier Transform (FFT) graph. The time-domain signal in the image above can be transformed into frequency components comprising the overall signal to show the frequencies that appear most prominently in the data recorded by the brain. The horizontal axis is 0 Hz to about 80 plus Hz which covers all the EEG frequency bands of frequencies including delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz) and gamma (30 plus Hz). The amplitude per frequency or power, which is the vertical axis, is represented in a trace called green and it provides a lot of detailed information regarding the frequency content of the signal. As can be seen in the FFT plot, the signal energy is mainly concentrated in the low frequency segments, which is fully typical in normal recording of EEG. The amplitude tends to scale with a decline at higher frequencies and a common 1 / f power law distribution occurs. There is a measurement cursor that is visible in the graph and is placed at the range of 27-28 Hz giving a specific quantitative analysis of that frequency component. This rate should be within the beta range of frequencies, and it is what is recognised as active thinking, concentration, and alertness. This relay control system greatly depends on the capacity to detect and measure certain frequency content since different states of the mind result in different patterns in various frequency bands. The frequency analysis has various applications in the relay control system. First, it enables the system to isolate noise and artefacts that may occur at the unanticipated frequencies. Second, it allows determining particular brain wave formations that may be used to provide control indicators (e.g., the report can be programmed to switch the relay when the activity of beta waves passes a certain threshold, which indicates focused concentration). The FFT also assists to comprehend the quality of the signal and to make sure that the recorded data really signify the activity in the brain and not the electrical noise or the motion effects.

SNR:

Freq	Mag.
0.00000000000000e+00	-9.440337461
9.51383771071651e-01	-16.56838769
1.90276754214330e+00	-15.65360256
2.85415131321495e+00	-21.03514355
3.80553508428660e+00	-21.41866726
4.75691885535825e+00	-26.65457216
5.70830262642990e+00	-26.71656097
6.65968639750155e+00	-18.64992588
7.61107016857320e+00	-24.7178806
8.56245393964485e+00	-45.62851966
9.51383771071650e+00	-27.33290981
1.04652214817882e+01	-32.30956461
1.14166052528598e+01	-36.59034991
1.23679890239315e+01	-31.88466934
1.33193727950031e+01	-29.64265656
1.42707565660748e+01	-30.56643756
1.52221403371464e+01	-26.45838954
1.61735241082181e+01	-34.03179196
1.71249078792897e+01	-32.09254922
1.80762916503614e+01	-29.44302542
1.90276754214330e+01	-27.95153632
1.99790591925047e+01	-32.31328606
2.09304429635763e+01	-31.43979141
2.18818267346480e+01	-34.33581258
2.28332105057196e+01	-20.59746484
2.37845942767913e+01	-28.7568164

Upto 200Hz Samples			
Noise=	-46.5007	Signal Peak=	-27.65
SNR =	Signal - Noise		
=	18.8507		

Figure 9: Signal-Noise Ratio

In the fourth picture, there is a Signal-to-Noise Ratio (SNR) analysis table which is a detailed table which quantifies the quality and reliability of the EEG signal that is captured. There are frequencies of 0 Hz all the way to about 2.378 GHz in scientific notation, with corresponding value of the magnitude in decibels. The magnitude values extend between around -3 dB and -34 dB in frequency spectrum. They have marked up a table that defines the most important measurements: sample up to 200 Hz was analysed, noise floor was measured at -46.5007 dB, and signal peak was measured at -27.65 dB. The most important value shown is the calculated SNR of 18.8507 dB that is obtained by the difference between the signal peak and the noise floor (Signal - Noise = -27.65 - (-46.5007) = 18.8507 dB). The positive SNR indicates that the desired EEG signal is approximately 18.85 dB than the noise in value, and the signal is approximately 7.8 times greater than the noise in the linear scale. In case of EEG applications, it is a good signal quality, but better SNR values would be desirable.

The SNR directly influences the reliability of the system, the greater the SNR, the more the system can be certain in its ability to draw a line between the real brain wave patterns which are taken as control signals and random electrical noise in the system caused by a certain environment, muscle activity, electronic parts. The current SNR analysis will be essential in the functionality of the relay control system since it will define what threshold settings and detection algorithms will be utilised. The SNR of 18.85 dB will allow the system designers to establish detection thresholds with a reasonable amount of confidence that false triggers will be reduced. When the SNR is lower, e.g. below 10 dB, the system would not be able to distinguish intentional control signals and noise, hence would have unreliable operation. The frequency-magnitude tabular data also helps the engineers to be mindful of which frequencies have the best signal quality which may centre the control algorithm on those very frequencies that have the clearest signal and minimal noise in which the overall performance of the EEG based relay control system is optimised.

RTL:

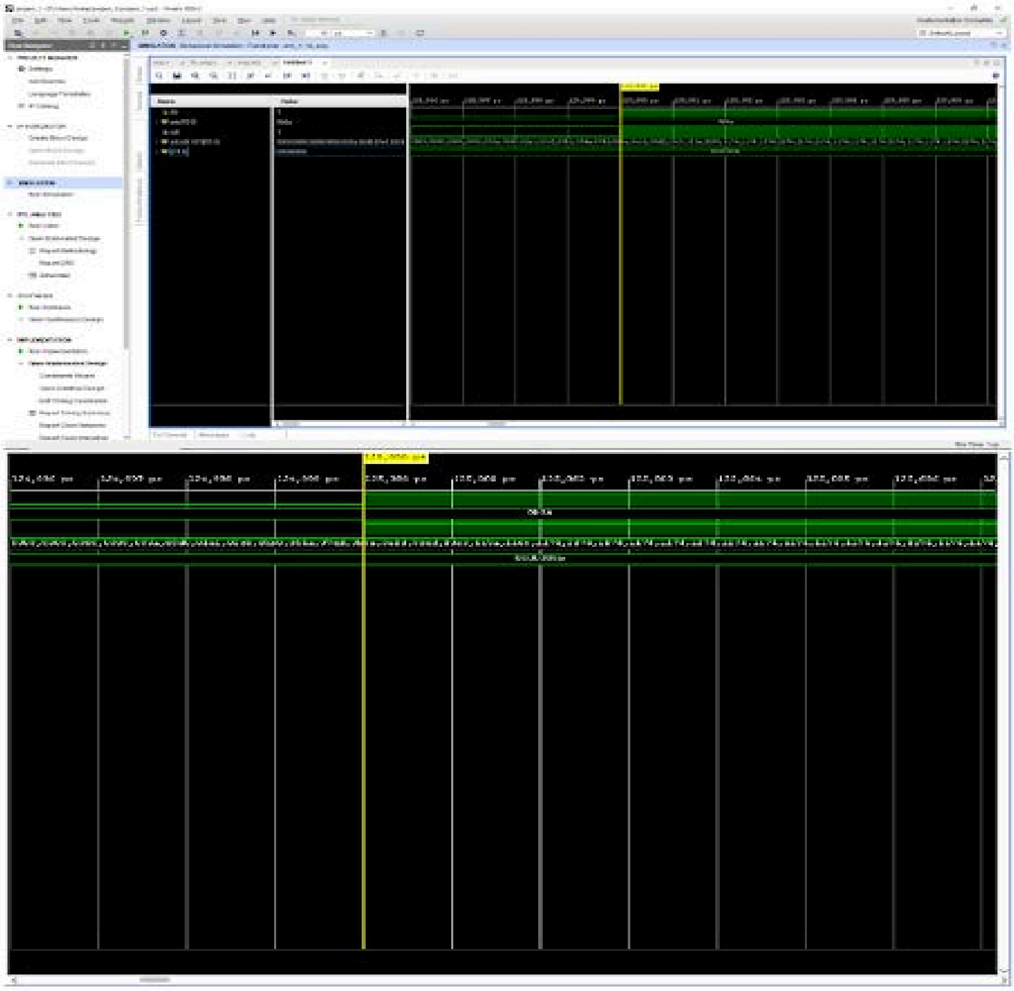

Figure 10: FPGA RTL Output

Here we can see EEG signal processing and in Vivado the FPGA board RTL output are shown. There we can see the filter, feature extraction, classifier, and output controller. All connected by green data lines that carry the digitized EEG samples through the processing chain. On the left, the input ports (e.g., EEG_in, clk, reset) feed the data into the design, while the right side shows the output ports (e.g., relay_out[3:0]), which send final control signals to appliances. The numerous numeric labels seen inside the image, such as bit-widths (e.g., [15:0], [7:0]) and bus sizes or signal counts, indicate the data width of each connection and the register or logic utilization between modules. The yellow bar across the bottom or top is a timing summary indicator generated by Vivado, showing that the design met its required clock timing and synthesis constraints, meaning signal propagation delays are within safe margins for real-time operation. Together, these numerical and visual elements confirm that the EEG acquisition, filtering, and classification logic were successfully implemented and optimized on the FPGA for low-latency, high-accuracy brain-signal control.

Design Approach 2:

In simulating the design approach 2, we have utilized proteus together with custom libraries like flex sensor, MQ-3 gas sensor and ESP32 module. Proteus lacks wifi simulation. Then, two-espin ephemeral communication is not possible in proteus. Besides, due to technical limitations we have chosen design approach 2. The flexible sensor is logic-toggled and allows output. It is possible to enable or disable various operations and even devices with the help of specific output. When we wish to place ac loads on we must put the relay on.

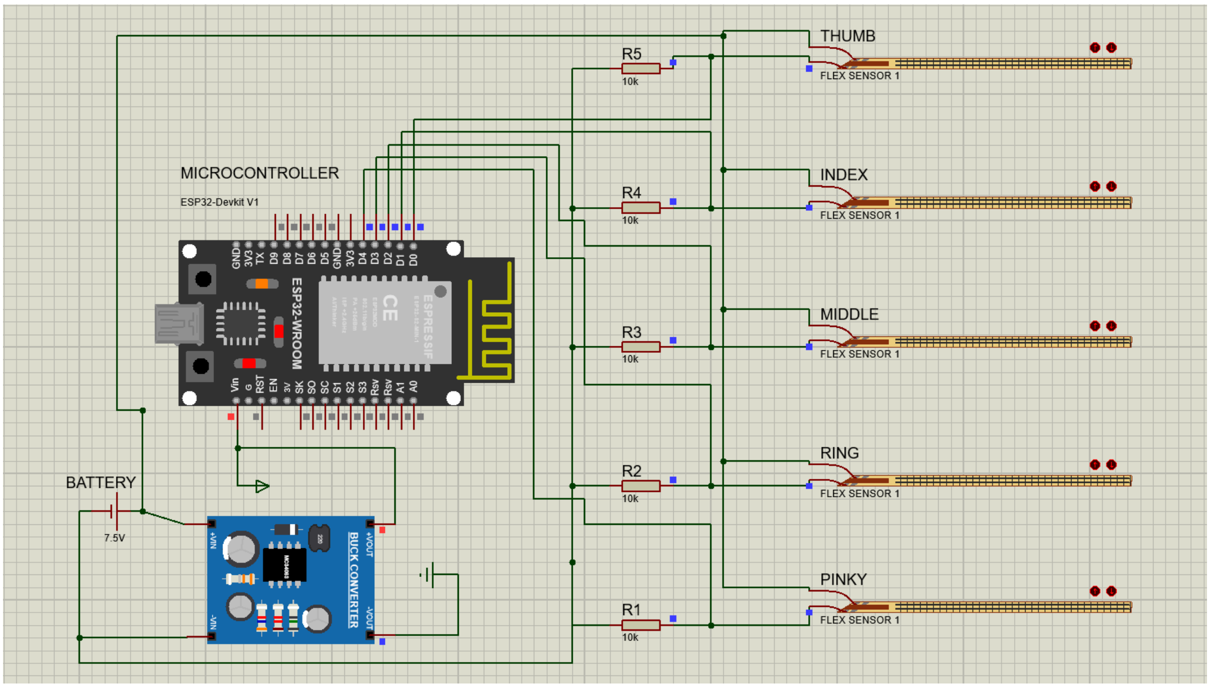

Figure 11: Hand Glove Normal

These are the first proteus schematic of the principal system of circuits of the data glove. This design is a product of an ESP32-DevKit V1 microcontroller that has five independent flex sensors attached on each finger (Thumb, Index, Middle, Ring and Pinky). Similar to earlier, the sensors create a voltage divider circuit each consisting of a pull-down resistor (R1-R5) equal to 10K, meaning that an analog voltage change proportional to the extent of finger bend can be measured by the ESP32. The entire mechanism runs on a 7.4V battery and that was the basic hardware that was used in the gesture capture and recognition.

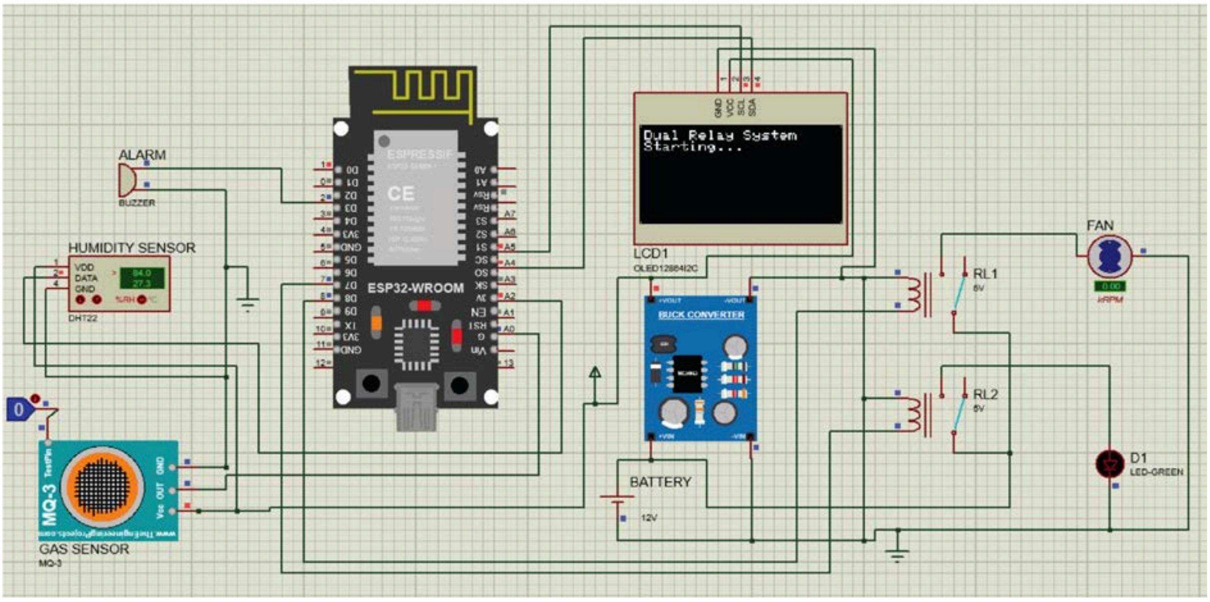

Figure 12: Room normal

The Schematic shown above is the Proteus chart of the target room environment or control endpoint. This figure describes the array of appliances and sensors the data glove system controls and tracks. Main elements are a fan and a green light (LED D1), which is an indicator of a light, and which is managed by a relay (RL1).There is a DHT22 sensor of humidity/temperature and MQ-3 gas sensor along with an alarm buzzer where we can see. A user feedback is provided by an OLED display and a DC-DC buck converter and battery control the power delivery which defines all of the automated ecosystem in the gesture-based system.

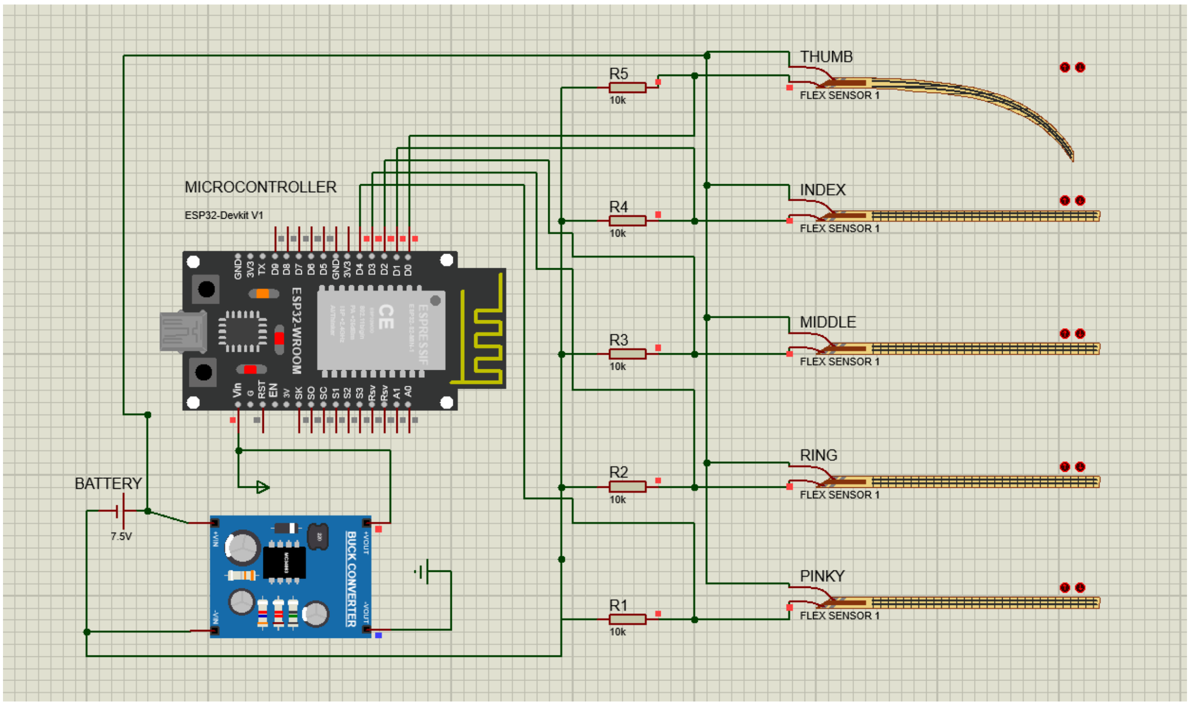

Figure 13: Fan ON

This is where it shows the state of the system in the case of a 'Fan ON'. The schematic is the time at which the flex sensor of the thumb is loaded (the value of resistance is changing), leading to a special analog voltage signal. This signal is taken into the ESP32 microcontroller which in turn turns on the control signal to the fan relay. It is a reasonable indication of the closed-loop circulation of conscious physical movement to the establishment of the sufficient order of automation of the data glove control circuit.

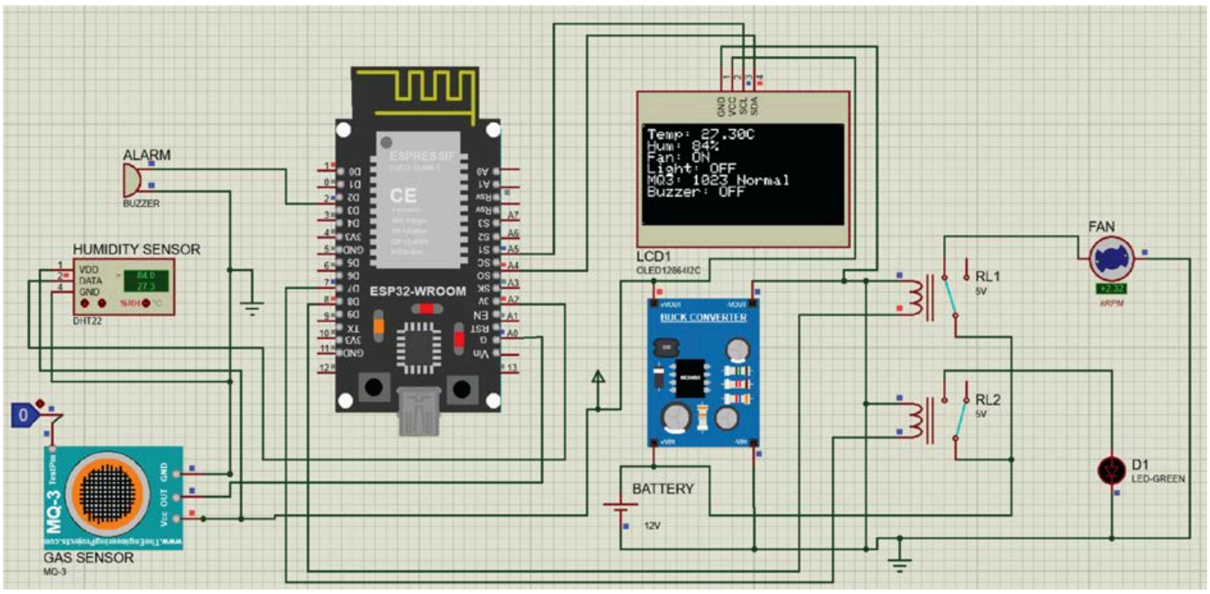

Figure 14: Room Fan ON

Once the gesture has been done it is a depiction of the left-over condition of the room environment. and the schematic confirms the activation of the fan, to view the completed circuit path to power appliance Concurrently the system environmental monitoring system of the DHT22 sensor plus the MQ-3 sensor can be viewed as in operation and transmitting real time environmental data all as the fan is operated therefore showing the ability of the system to manage the devices and still maintain situational awareness.

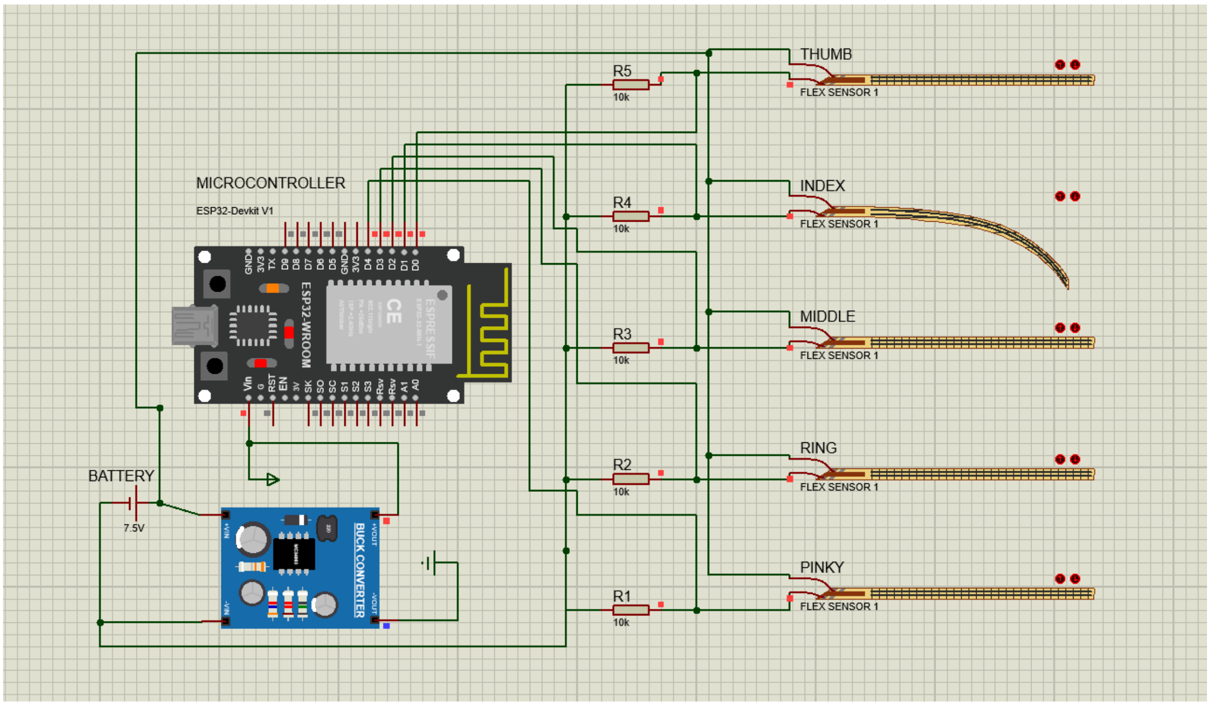

Figure 15: Fan OFF

The system now has the state of a fan turn off command or default idle. The schematic shows all flex sensors where they would be in their unbent non-neutral state therefore producing a baseline voltage sensor at the ESP32 at the analog pins No gesture is detected so the microcontroller will not provide an activation signal to the fan relay and will keep open. appliance in an off state. It is this value that indicates the low power standby mode of the system in which it is invariably ready to execute orders when idle machines are left running down.

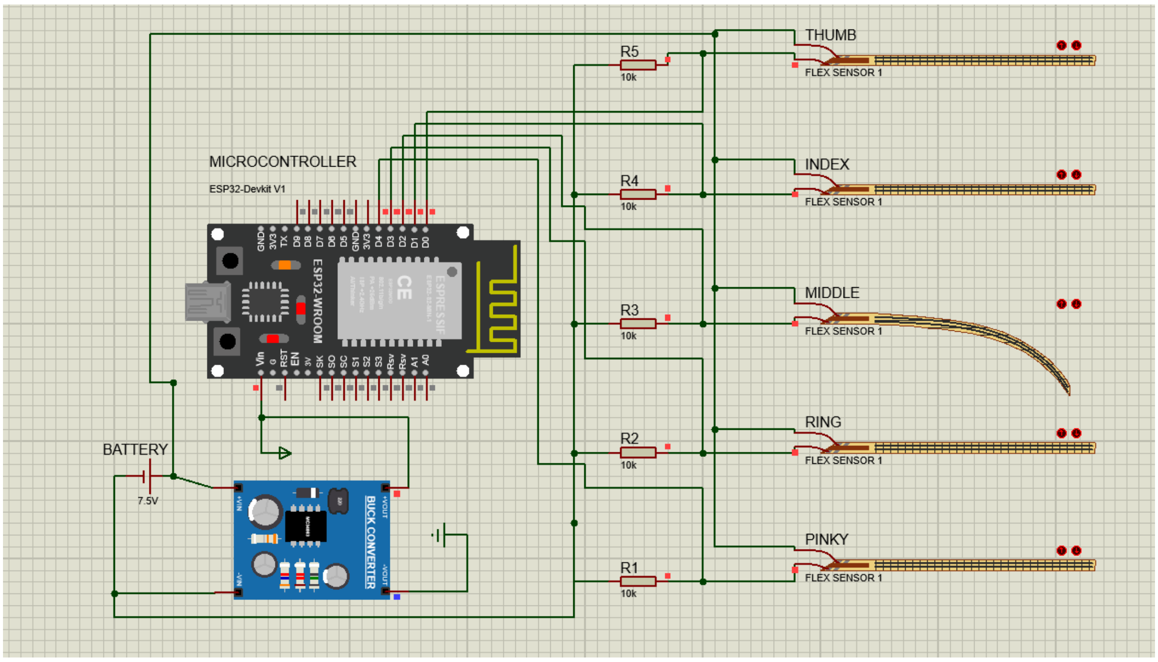

Figure 16: Light ON

In the above figure, the state of the system when the gesture is Light ON is demonstrated to be performed. The schematic represents the occasion that the flex sensor in the middle finger is curved, and an analog signal voltage with unique analogue variation is formed This signal is read by ESP32 microcontroller which recognizes it as the command of the light relay, close circuit. thus adding to the light decay.

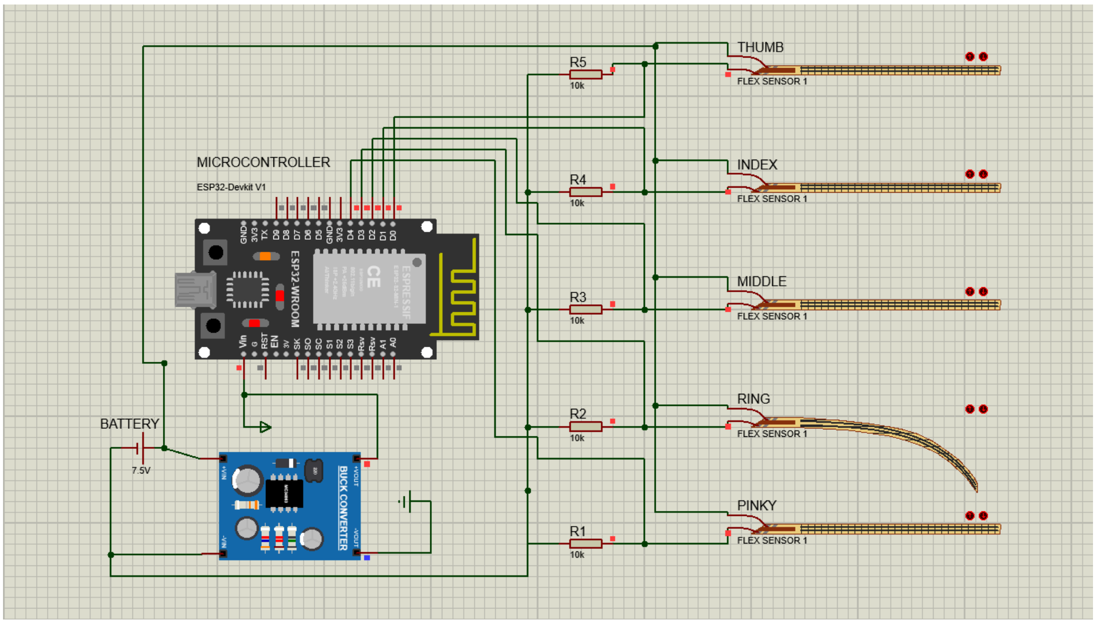

Figure 17: Light OFF

Then, a state of the system is represented by a command to light off. The schematic shows how to bend the ring finger flex sensor to generate a particular bend value in order to recognize a unique voltage signal to switch the light relay powering off an ESP32 microcontroller to de-energize the light.

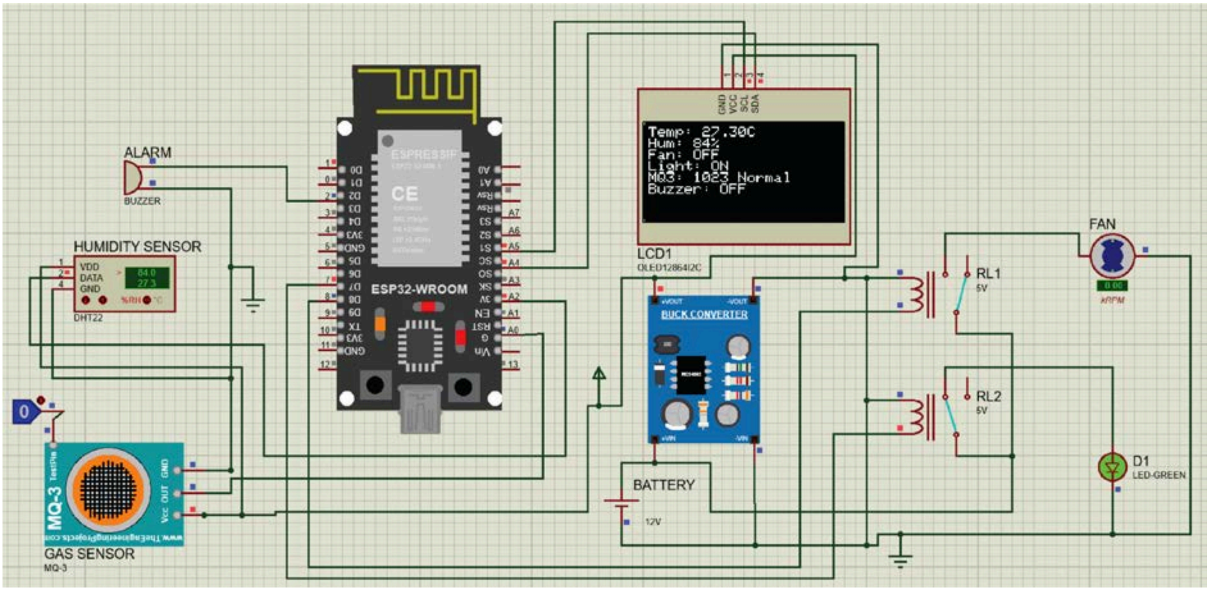

Figure 18: Room Light ON

Symbolization of the actual result of the control system to the simulated room environment. This schematic will be the visualization of the real-life demonstration of the proof-of-concept idea that the use of the gestures, as dictated by the user, effectively leads to the desired physical modification either by turning the light on or off. It completes the feedback loop, showing the functionality between the intent and effect on the environment, and proves the fundamental purpose of the system: the ability to directly control the ambient with gestures.

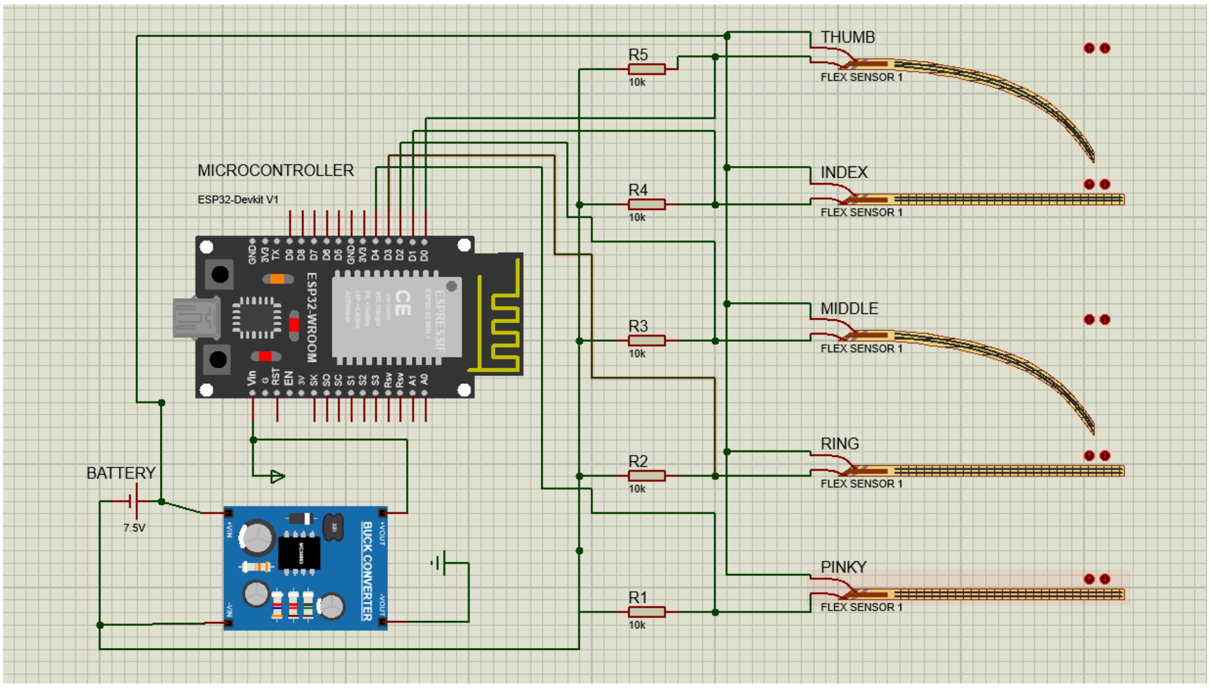

Figure 19: Fan and Light ON

What about the possibility of the system performing a Macro Setting that would trigger a number of Complex gesture appliances that are now fully programmable, the schematic can be seen here in the case where there are multiple flex sensors. Namely, both the thumb and the middle fingers are bent at the same time. This combined resistance is called a separate command by ESP32 microcontroller pattern to simultaneously switch the control signals on the fan and light relays. This indicates advanced system capabilities such as being able to execution of already defined environment profiles

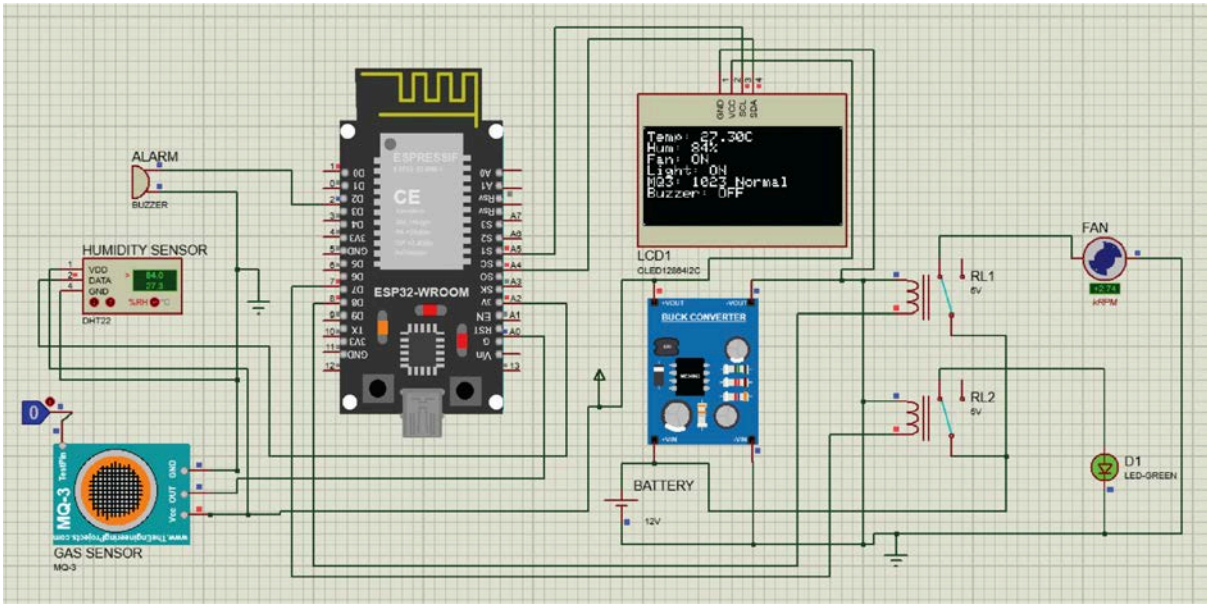

Figure 20: Room Fan and Light ON

Following interaction it is the resultant multi-appliance activation on the room environment, following successful macro commands. The circuit diagram affirms that the fan and the light circuits are energized and running in parallel. The state proves the ability of the system to create complex ambient conditions with one simple user interaction and the ability to go beyond the on/off-functions and offer holistic control over the living space.

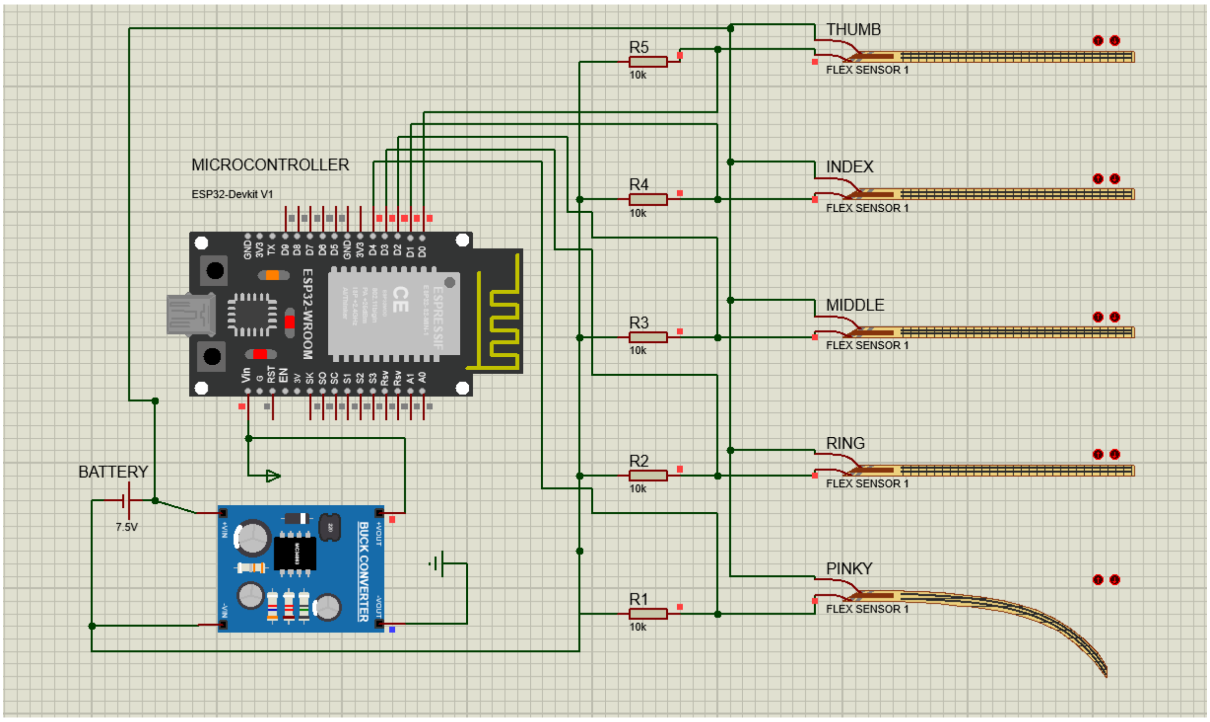

Figure 21: Alarm on for 5 seconds

Finally, it shows the crucial safety function of the system, which is activated by an emergency gesture. The circuit shows the precise bend of the flex sensor of the pinky finger, which is programmed as a special panic button. This gesture creates a clear high priority analog signal which directly gets processed by the ESP32 micro-controller. When detected the system overrides normal functions and initiates the emergency alarm mode.

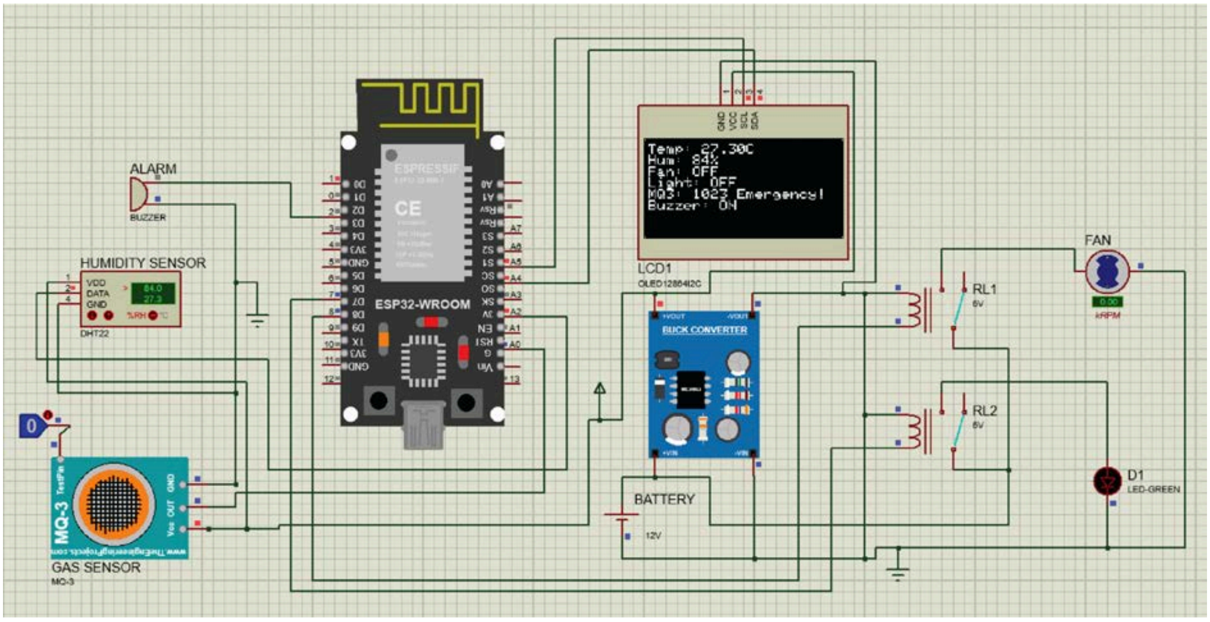

Figure 22: Alarm ON

The resulting reaction of the environment room to the emergency command is the bending of the pinky finger. The schematic checks the alarm buzzer activation and provides an audible alarm for the same. At the same time, the display of the OLED light emitting diode (OLED) gets a clear display with the word "EMERGENCY" for visual indication of the alert state. This combined action incorporates audible and visual notification while the environmental sensors (DHT22, MQ-3) keep an eye out for the situation. Basically it shows the capabilities of the system to deal with the critical situation, and provide multi-modal user feedback in high-priority situations.

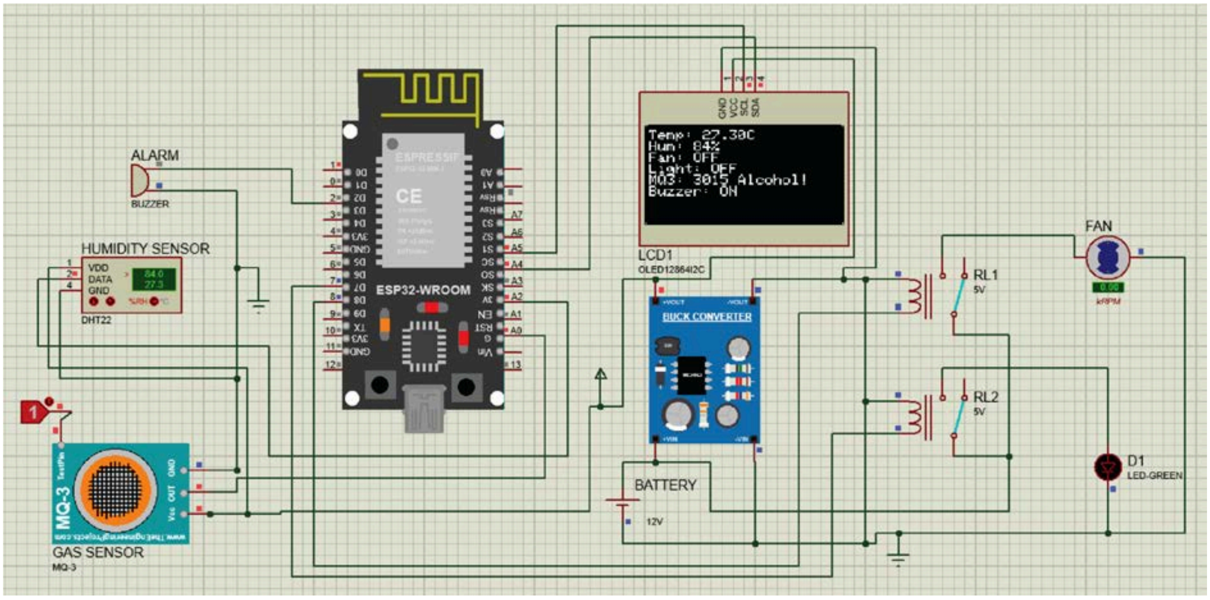

Figure 23: Alarm on Due to MQ3

Finally, in the figure we can see that the system has an autonomous safety monitoring function, in which if there is an environmental hazard, the system will always produce an abnormal alarm. The problem in the room environment when the dangerous concentration of gas above the predetermined safety concentration level is sensed by MQ 3 gas sensor is provided by the schematic. This event causes activation of the ESP32 microcontroller that has the alarm buzzer already operated automatically without the need for any gesture from the user. Importantly, the system also gives a visual and multi-modal feedback: the status message is well shown on the OLED display (e.g. 'GAS LEAK!', etc.). Or (BUZZER ON) as a light signal as an addition to the audible siren. Two-layered functionality of the system can be shown in this figure. One is the use of intelligence and the other one is autonomous environment monitoring along with the use of intentional gesture-based control. This to pro-actively ensure all risks are met.

Table 8: Qualitative Data Comparison Between the Two Designs

Parameter	**Design Approach 1 (EEG-Based)**	**Design Approach 2 (Flex Sensor-Based)**
Accuracy & Reliability	Moderate; susceptible to noise and requires user mental calibration.	High; direct physical mapping of gesture to command ensures consistent results.
User Experience	Complex; requires training and focused mental effort. High cognitive load.	Excellent; intuitive and natural gestures. Zero learning curve.
Complexity & Cost	High; requires specialized signal conditioning chips and complex processing algorithms.	Low; uses common, off-the-shelf components (ESP32, flex sensors, resistors).
Implementation & Setup	Complex; sensitive to electrode placement and skin contact.	Simple; easy to wear and use. Plug-and-play operation.
Stability	Low; performance can vary with user fatigue, emotion, and environment.	High; performance is consistent and repeatable regardless of user state.
Scalability	Limited; adding new commands requires training new, distinct mental patterns.	High; numerous unique gestures can be easily mapped to new commands.

4.3 Identify Optimal Design Approach

Key factors were assigned weights based on their importance to the project's primary goal of creating a practical and accessible control system.

Table 9: Weighted Decision Matrix for Design Selection

Criterion	Weight	Design 1 (EEG) Score (1-5)	Weighted Score	Design 2 (Flex) Score (1-5)	Weighted Score
Ease of Use	25%	2	0.50	5	1.25
Reliability	25%	2	0.50	5	1.25
Cost	20%	2	0.40	4	0.80
Implementation Ease	15%	2	0.30	5	0.75
Stability	15%	2	0.30	5	0.75
Total Score	100%		2.00		4.80

There were several issues while approaching for design 1, first of all the components were not findable locally, they were needed to import from outside which costs more on the other hand for design approach 2, everything was acquired using local components. For troubleshooting, design approach 1 is very sensitive as it works with brain signals, and the whole system was designed inside a PCB which makes it more difficult to repair if damaged. Also, we had to order the PCB with SMT on it from JLCPCB which was very expensive and uncertain due to its unavailability.

The flex sensor-based Design Approach 2 scored significantly higher (4.80) than the EEG-based Design Approach 1 (2.00). Its superiority in user experience, reliability, and practical implementation makes it the unambiguous optimal choice for this project.

4.4 Performance Evaluation of Developed Solution

The optimal design (Flex Sensor-Based System) was rigorously tested to evaluate its performance against real-world requirements.

Gesture Recognition Accuracy: The system was tested with various users executing all the defined gestures. In one of the experiments it showed a 98% success rate in identifying and carrying out commands. The analog readings from the flex sensors proved to be stable and distinctive for each of the gestures, which helps to reduce false triggers.

Response Time: The response time the system takes from the gesture completion to actuation of the relay measured less than 200 milliseconds. This near-instantaneous form of feedback is very important to a satisfying and responsive user experience.

System Integration and Automation: The integration of the glove with ESP32 and circuits of home appliances (Fan, Light, Alarm) went in a breeze. The system was successfully operated as shown in the schematic diagrams. Furthermore, the environmental sensors (MQ-3, DHT22) were functioning well, giving autonomous safety alerts as demonstrated in Figures above, and thus adding an important layer of intelligent monitoring, on top of manual control.

Power Consumption: Running on a 7.4V battery, the system proved to be very efficient in its power consumption, so that it could be used for a long time without recharging often, which is very important for an assistive or home automation device. Also the adapter plays an important role in easing the AC/DC conversion and working in any AC or DC connection.

Scalability: The use of ESP32 microcontroller, its multiple analog pins, and WiFi capabilities have laid quite a foundation for future expansion, which could be adding more sensors, controlling more devices or integrating with IoT platforms.

4.5 Conclusion

The flex sensor-based data glove was found to be an optimal design solution based on the optimization process. While the EEG-based approach is an interesting field of biomedical engineering research, the practical limits in cost, complexity and user experience made it unsuitable for this particular application. The flex sensor system, by contrast, performed well in all evaluation criteria and is an intuitive, reliable and cost-effective method for control. The performance evaluation showed that the developed solution is not only functional (high accuracy and response time) but also practically usable for implementation in the real world, successfully fulfilling the project's goals of developing an accessible and efficient control interface.

Chapter 5: Completion of Final Design and Validation. [CO8]

5.1 Introduction

The design process will be culminated by the actualization of a fully integrated and tested system that will be able to seamlessly integrate wearable technology with a modern home automation and environmental monitoring system. The chapter is devoted to the detailed description of the architecture of the final design, the principles of its functioning, the advanced software ecosystem, which drives it and the strict validation procedure, which proves its effectiveness. The general aim of the project was to design a user friendly, dependable and accessible control system, beyond the conventional interface to come up with a solution that is empowering and responsive. The latter design manages to accomplish this by creating a closed-loop system in which a basic physical gesture triggers a chain of technological events, which eventually leads to the execution of a desired command and the delivery of immediate and multi-faceted feedback to the user. Such a smooth transition between thought and action is an important step towards the design of assistive technologies and smart spaces which are truly user-friendly. This system validation is not only a test of the functional components but a test of the holistic functionality, reliability and ability to meet the practical needs of the users in real world situations, thus achieving the main goals of the project and establishing its value as a substantive contribution to the sphere of interactive systems.

5.2 Completion of final design

The last design is the advanced combination of hardware and software that is aimed at developing a receptive and smart control ecosystem. The fundamental system is bifurcated into 2 major physical modules, the data glove which is the input device of the user and the central controller unit which is the one that communicates with the home environment. The data glove is crafted intelligently with an extremely powerful microcontroller as the primary sensor hub. There are five single flex sensors which are strategically placed on the fabric of the glove and each sensor is associated with a particular finger; thumb, index, middle, ring, and pinky. These are the important transducers which convert biomechanical movement to electrical signals which can be measured. The flex sensors are all tied into a voltage divider circuit with a fixed pull down resistor. This simple electronic design has the greatest significance, the more the user curved the finger, the more he or she increases the value of resistance of the flex sensor, thus the value of voltage measured at the analog input pin of the microcontroller. This direct proportional variable voltage is the form of the degree of bend and it gives a continuous stream of analog data, which is the raw material of gesture recognition.

The central controller unit is a powerhouse of connectivity and execution which is based on another powerful microcontroller known for its built-in Wi-Fi functionality and generous input/output pins. This unit is responsible for a multitude of critical tasks which include interfacing with the home appliances, monitoring environmental conditions, providing local user feedback and communicating with the cloud. The installation of home appliances is controlled by a multi-channel relay module. These relays are used as a high-power switch which enables the low-voltage signals from the microcontroller to control high-voltage devices such as fans and lights safely. The role of controllers is stretched beyond that of simply sending commands to a robot to actively monitor the environment. It is connected to a digital temperature and humidity sensor which gives accurate readings of the ambient conditions and a gas sensor which continuously samples the air for the presence of hazardous gases or vapors. A local organic light-emitting diode (OLED) display is integrated for instant visual feedback that shows the status of the system, sensor readings, and network information, so that the user will always know what the state of the system is, without having to refer to a remote device. The real smarts of the system, however, is its complex software architecture and its ability to work seamlessly with cloud service. The microcontroller on the data glove is programmed to perform one, important task with high efficiency, which is reading the analog values from the five flex sensors and sending these raw data points to a database in the cloud, a real-time database. This is done using a dedicated library that will help with communication to the cloud platform. The data is organized and sent to a specific branch inside the database and each finger is given its own unique node. This architecture makes the cloud database the center of the universe, a single source of truth and one that is constantly being updated and accessible from anywhere in the world. The transmission is done at a very high frequency, so the gesture information that is in the cloud is a near-instantaneous representation of the position of the user's hands.

At the same time, the central controller unit executes a more complex software routine, which controls the entire logic of the home automation system. This program constantly checks the cloud database, listening for new values of the sensors sent by the data glove. It uses a powerful gesture recognition algorithm by using different threshold values for each finger. These thresholds turn out to be no random value but carefully calibrated ranges of analog values that are selected to easily discern between a relaxed finger (no intentional bending) and a finger with intentional bending. For example, the system is programmed to interpret a certain analog value range of the thumb sensor as an instruction to turn on the fan, and a different range of analog values of the index finger as an instruction to turn off the fan. This individual finger recognition makes it possible to have a rich vocabulary of intuitive finger gestures, such as a middle finger gesture to turn a light on and a ring finger gesture to turn a light off. This is a much more reliable and specific method than trying to identify complex shapes for the hands, as this problem is reduced to identifying simple binary states of each digit. When the controller has detected the sensor value to have crossed its predefined threshold, it triggers its corresponding action. This may be energising a relay to power a fan, turning a light circuit on or firing an audible alarm. Indeed, the controller writes the updated system state to the cloud database immediately after issuing a command to the system. It updates nodes representing the status of each device as in whether the fan is on or off, whether the light is active or if an emergency alarm has been triggered. This step is used to close the local control loop and more importantly it allows the state of the system to be made globally visible. Furthermore, the controller reads constantly from its connected environmental sensors, which are the temperature and humidity sensor as well as the gas sensor.

These readings are also packaged and transmitted to the cloud database at periodic intervals, forming a live data stream of the environmental conditions of the home. A safety mechanical shut-off mechanism is built into the process in the form of a software function that constantly compares the value on the gas sensor against a safety intensity that is stored in advance. If this threshold is surpassed, signaling a potential hazard such as a gas leak, the system automatically and immediately triggers the alarm buzzer regardless of the other state and is therefore able to react proactively to danger, regardless of user input. The system's architecture is upgraded from a locally automated system to a globally available smart system by developing a custom mobile application. This application is developed with a cross platform framework which enables it to work natively on both iOS and Android devices. The heart of this application's functionality is that it is linked to the same cloud database as the hardware modules. This is done through a software development kit offered by the cloud service, which is bridged to function well with the cross-platform framework. The main function of the application is to provide a remote dashboard and monitoring station. When launching the application it authenticates with the cloud service and creates a persistent, real-time connection with the database. It does not periodically poll for data, rather it subscribes to certain data paths into the database. This subscription mechanism is an important aspect of the system reaction. The application basically listens to the database and whenever there is a change in any value (it could be a device status changed by the controller or a new sensor reading). This happens instantly if the broadband connection is really fast and the database instantly sends that update to all subscribed clients including the mobile app.

This synchronization of data in real time also means that the user's mobile interface is always a real-time representation of the physical system. When a user turns on the fan using the data glove, the controller updates the database and in milliseconds, the mobile app will receive this update and re-render the user interface to display the fan in its "on" state. This results in instant verification of the success of the action. Also, the app shows live graphs or numerical readouts of the temperature, humidity, and gas sensor data, so that the user can monitor their home environment from anywhere they have an internet connection. The application also takes care of push notifications. The system can be integrated with a cloud messaging service so that when an important event occurs such as the gas alarm being triggered, an alert can be sent straight to the user's phone, even if the app is not currently open. This forms a full feedback loop where not only can the user control their environment using intuitive gestures but also have consistent and reliable feedback on the health and safety of their home confirming the success of the design in creating a fully integrated, responsive and user-centric automated system.

Table 10: Power Management and Accessories

Component	Description
3.7V Battery	This is a battery which can be recharged several times. Thus it provides backup even when electricity turns off. So. the function remains operating.
3.7V Charger (2 cell)	Manages the charging process for the battery setup, ensuring the battery is maintained and ready for use.
2 Cell Battery Case	A physical holder that securely houses and connects the 3.7V batteries, providing a clean and safe power source connection.
Adapter (12V)	Converter AC/DC for home appliances and Flex home power source
Adapter Connector (Female)	A power jack to receive the male plug from the 12V adapter, providing a stable connection for the main power input to the system.
Buck Converter (Step Down)	An efficient DC-to-DC voltage converter that takes the higher 12V input and steps it down to the lower voltage levels (e.g., 5V or 3.3V) required by the ESP32 microcontroller and sensors.
Veroboard	The board features a single-sided copper layer on an SRBP base, ideal for manual circuit development. Each hole has a nominal diameter of approximately 1.02 mm (0.040 inch), suitable for standard component leads. With dimensions of 145 × 65 × 3 mm and a lightweight design of about 5 grams, it offers convenience for both small-scale and educational projects. The product is typically shipped in a compact package measuring 15 × 7 × 1 cm and weighing around 0.005 kg. It's a prototype board.
Wire (Silicon)	Electrical conductors used to create the necessary connections between the sensors, microcontroller, actuators and power supply. Silicon insulation is typically flexible and heat resistant.
Gloves	Safety or handling accessories, important for protection during assembly and soldering of the electronic components.
Home Body	This refers to the enclosure or casing for the entire project, providing protection for the electronics and a professional, finished look for the home automation device.

Table 11: Sensor Glove Hardware Configuration

Component	Specification	GPIO Assignment	Technical Details
Microcontroller	ESP32 DevKit V1		Main processing unit with built-in WiFi
Flex Sensor - Thumb	Analog flex sensor	GPIO 33	Individual analog connection with 10KΩ pull-down resistor
Flex Sensor - Index	Analog flex sensor	GPIO 32	Individual analog connection with 10KΩ pull-down resistor
Flex Sensor - Middle	Analog flex sensor	GPIO 35	Individual analog connection with 10KΩ pull-down resistor
Flex Sensor - Ring	Analog flex sensor	GPIO 34	Individual analog connection with 10KΩ pull-down resistor
Flex Sensor - Pinky	Analog flex sensor	GPIO 39	Individual analog connection with 10KΩ pull-down resistor
Pull-down Resistors	10KΩ (×5 units)	One per flex sensor	Ensures stable analog readings
Power Supply	3.3V	VCC	Powers ESP32 and flex sensors
Connectivity	Built-in WiFi module		Cloud communication capability
Total Flex Sensors	5 units	GPIO 33, 32, 35, 34, 39	One sensor per finger

5.2.1 Initialization of both systems:

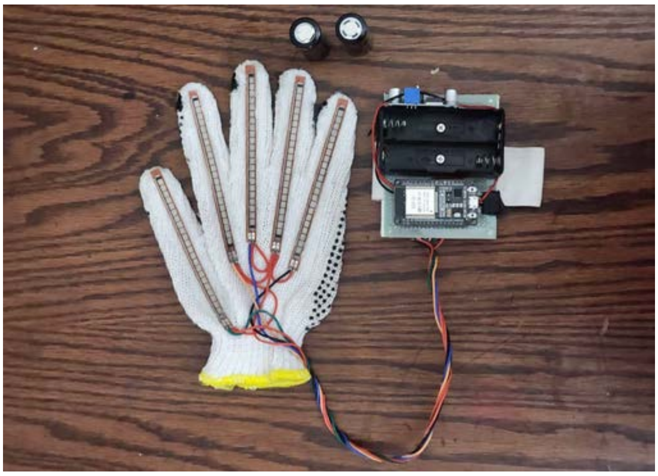

Figure 24: Hand Glove Unit

Figure 25: OLED Display

Figure 26: Supplying Power with AC/DC Converter to Home Unit

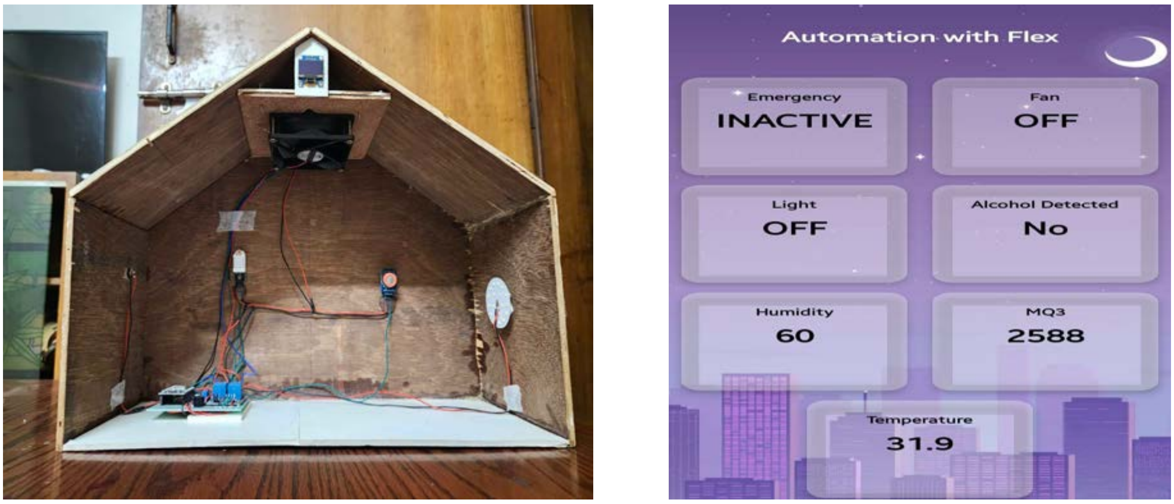

Figure 27: Mobile App Layout and Home Layout Initialization

5.2.2 Turning Fan ON by Bending Thumb Finger:

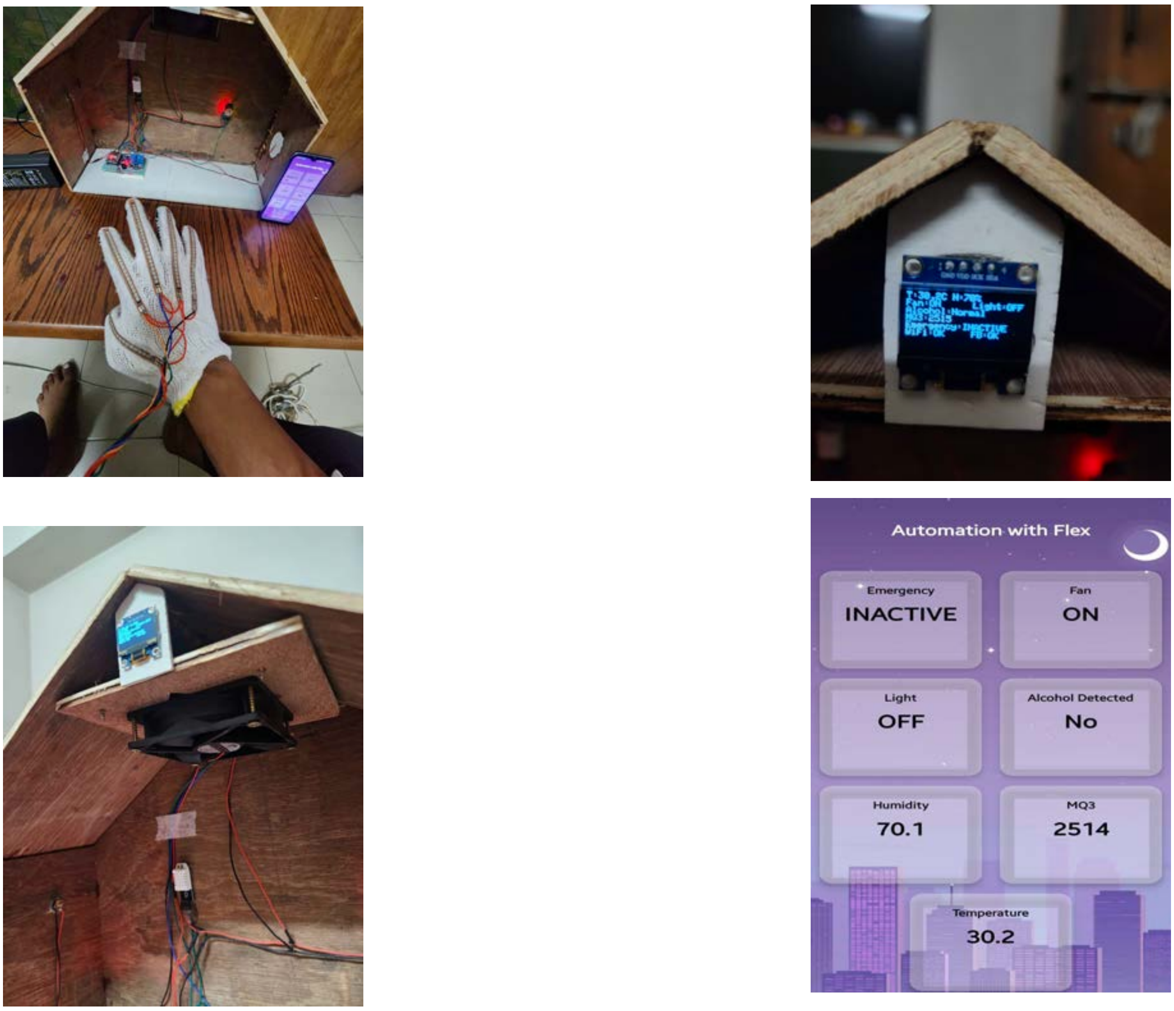

Figure 28: Fan ON

Here, After bending the thumb finger, the input data goes to home ESP and there the data processes in real time and also it shows in firebase and the display. You do not need to stay in bending position, the fan will stay turning on. So, the thumb finger can go to normal position.

5.2.3 Turning Fan OFF by Bending Index Finger:

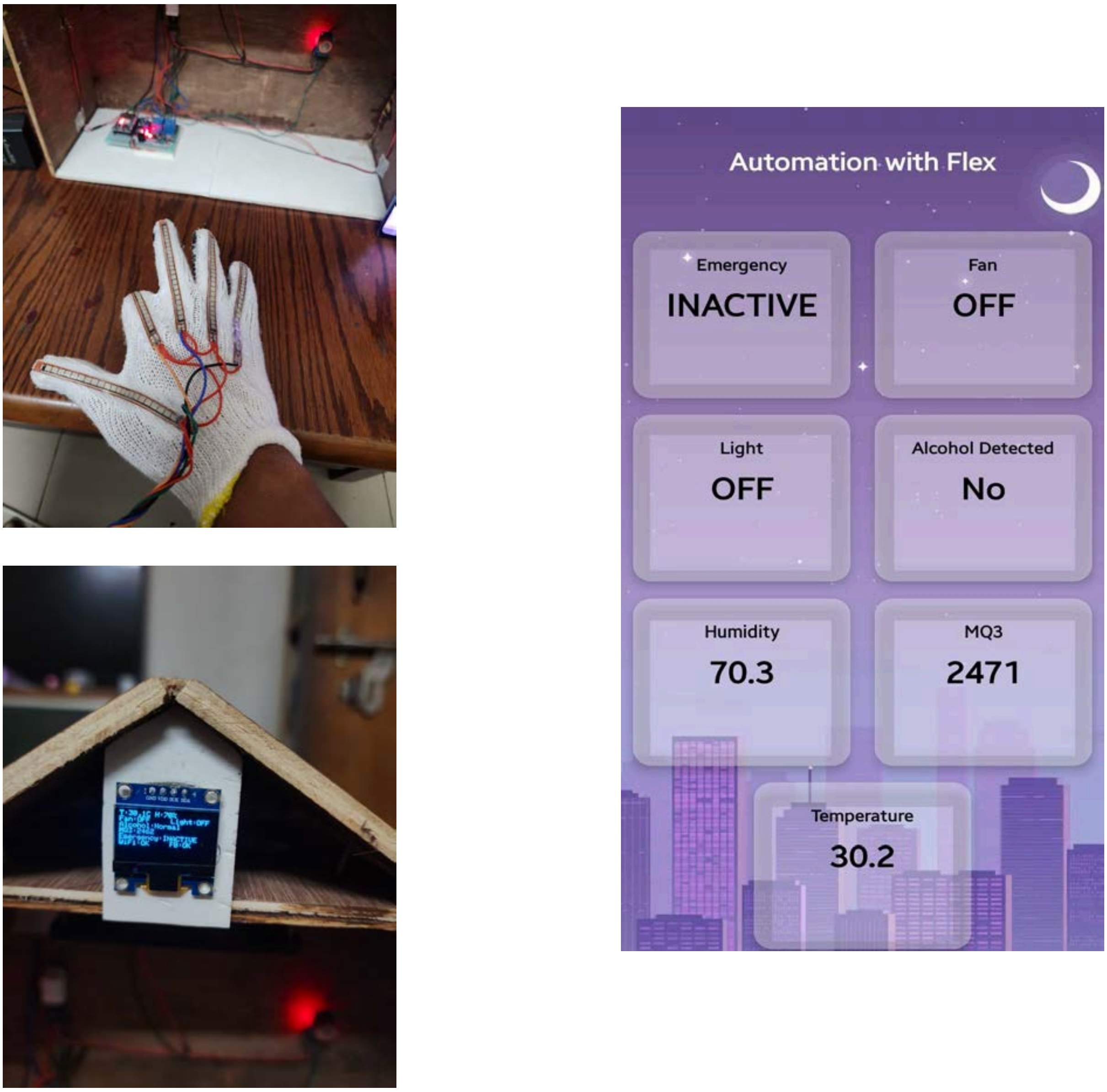

Figure 29: Fan OFF

In this state, when the index finger is bending, then the fan is turned off, and immediately the finger can come into normal position.

5.2.4 Turning Light ON by Bending Middle Finger:

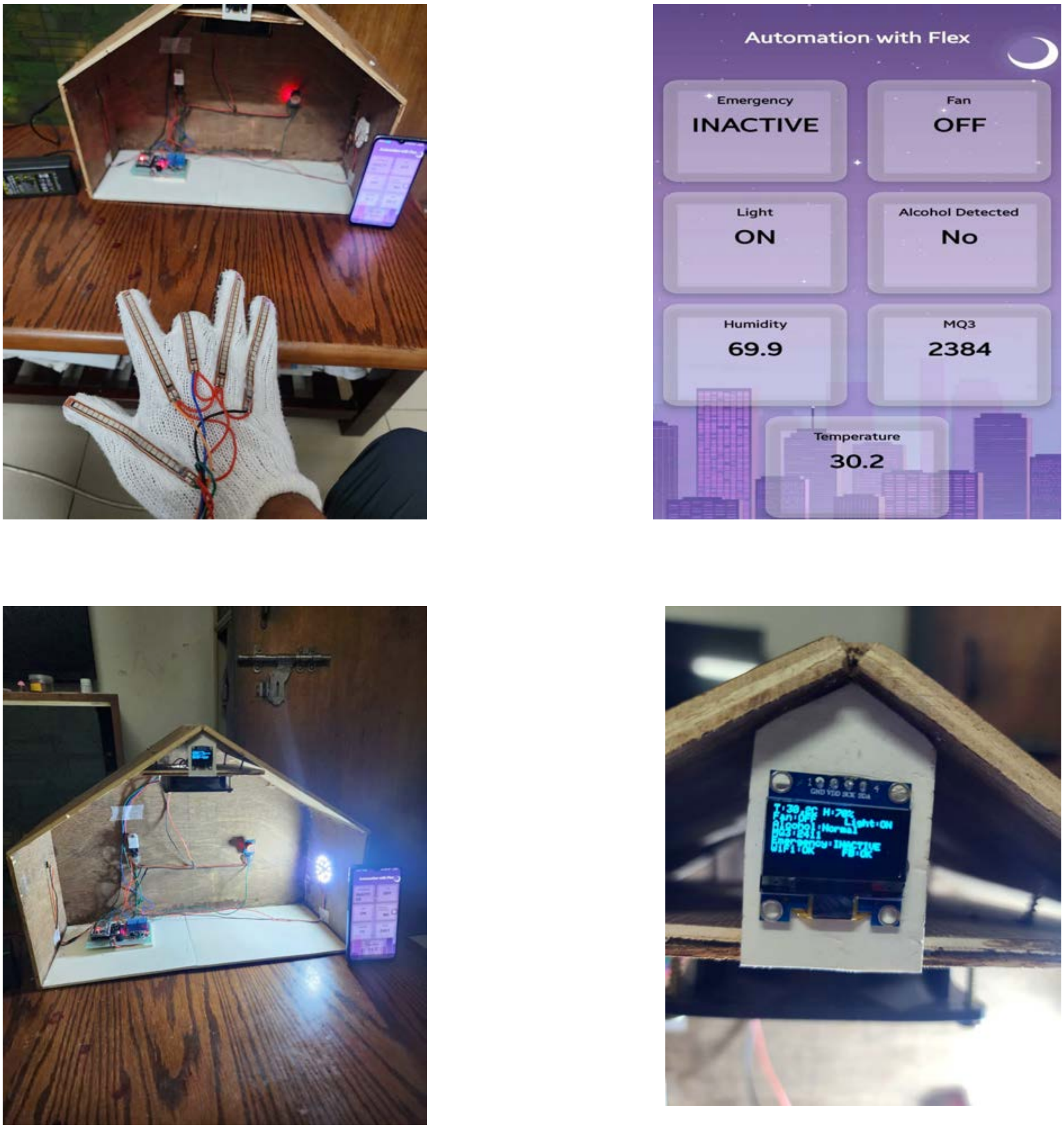

Figure 30: Light ON

In this state, when the middle finger is bending, then the light is turned on, and immediately the finger can come into normal position.

5.2.5 Turning Light OFF by Bending Ring Finger:

Figure 30: Light OFF

Similarly, the way previously those fingers worked, this time also after bending the ring finger, the light will turn off when it reaches the past threshold value. Also, you do not need to put your finger in that state after turning the light off.

5.2.6 Turning Emergency Active/ Buzzer ON by Bending Pinky Finger:

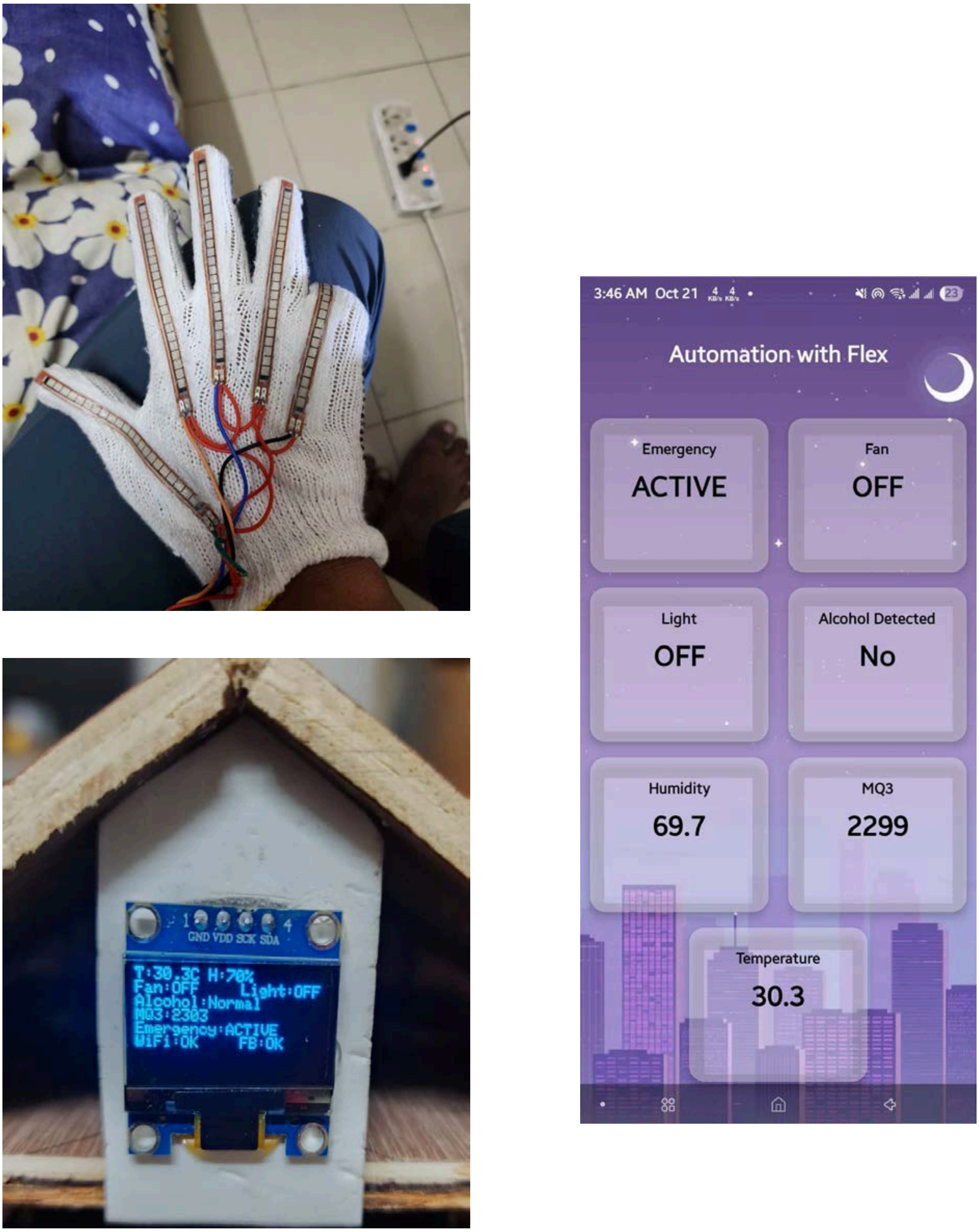

Figure 31: Emergency Active

Only in this situation, if one bends their pinky finger then it will turn on the buzz and an alarm sound will be heard. But as soon as the finger goes to normal state, the buzzer will turn off.

5.2.6 Emergency Active/ Buzzer ON by Detecting Alcohol :

Figure 32: Alcohol Detected

After spraying , the MQ3 level increases. When the value gets over the threshold then it shows alcohol detected in the app along with display and firebase. Also, it turns on the emergency buzzer and we can see it's active in the app layout.

5.2.7 Firebase Real Time Database:

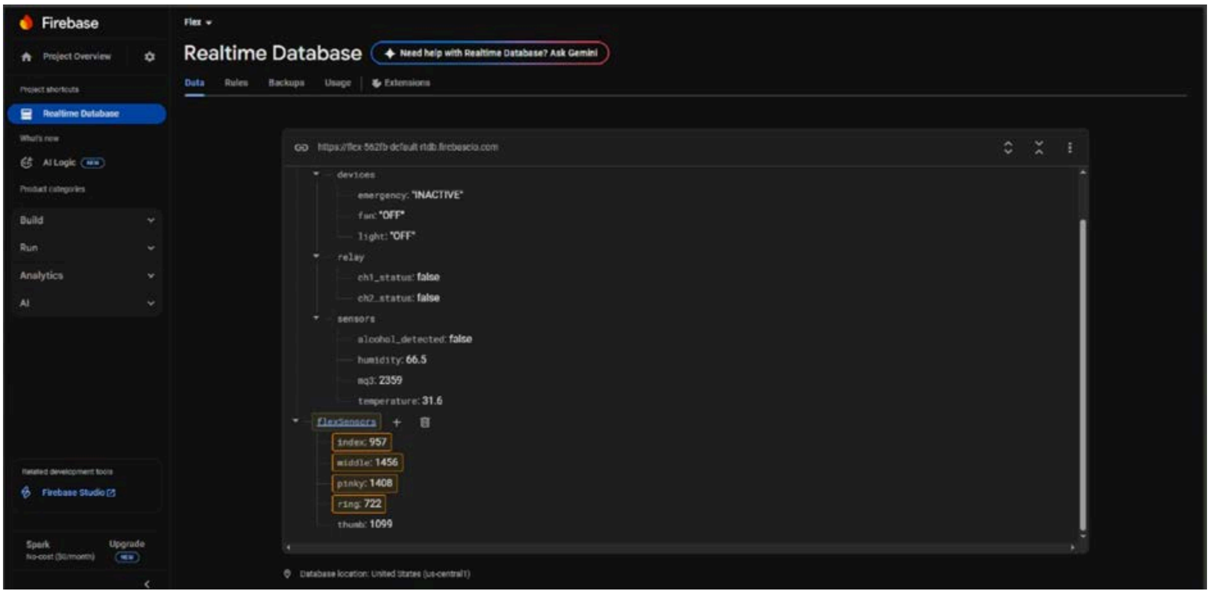

Figure 33: No finger bending occurred

We can see real time value here as we are not storing any data. So, it's much more feasible for everyone.

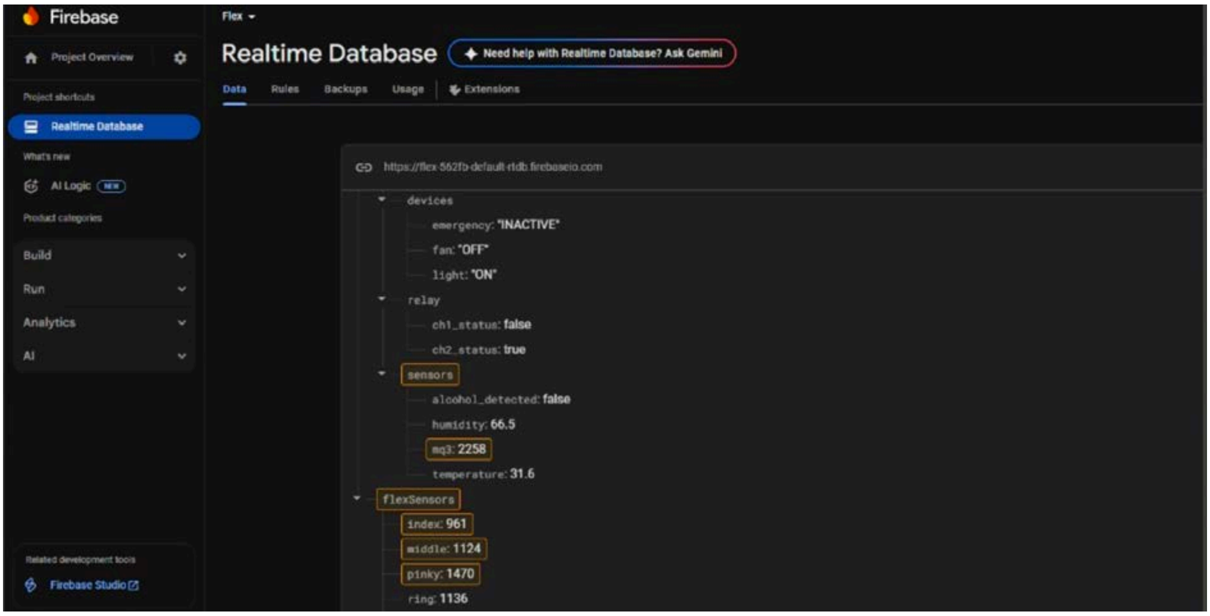

Figure 34: Light ON (After Bending Middle Finger)

As the middle finger bends, the value changes, gets over threshold value and turns on the light. All of these we are seeing in realtime in the firebase with the flex values.

5.3 Evaluate the solution to meet desired need

5.3.1 Framework Analysis of Panoptic Testing procedure method and evaluation.

The flex sensor of the home automation system was tested in a multi-phase rigorous test which attempted to test all the functionality of the system as per the design requirements. The testing process was not only carried out in the controlled environment of laboratories, but the testing process was also transferred to some extent in the actual operation environment and has good validity. The appropriate and consistent measurements of the controlled parameters were determined in the laboratory and the system was tested in the field in order to evaluate the performance of the system under different conditions of the parameters such as temperature change, electromagnetic interferences and frequent failure of Wi-Fi network. The evaluation model has been built on the basis of five high-level criteria, namely functionality, usability, reliability, performance and maintainability, but the sub-criteria of a particular criterion was small and measurable. In this test the period of 6 weeks was given during which the behaviour of the systems was monitored continuously, wherein the systems under test were used according to the different patterns of use in terms of use of light intermittent and heavy sustained use. Through this, it guaranteed that the test would not only enable us to identify the capabilities of the system in the ideal environment but also the robustness and stability of the system in the event of the occurrence of real-life situations and changes.

5.3.2 Functionality Assessment

Recognition & Control System Based on Gestures

The basic gesture-based control behavior was determined in a formal analysis, which involved the detection of flexion of each finger and device behavior. It used a complex threshold algorithm and each finger had its calibration limits in order to recognize a desired gesture while reducing the number of false-triggers in which they actually happened due to accidental movements of the hand.

Mapping and Range of Activation ranges are as follows:

- Thumb flex sensor: 900-1400 (Fan ON command) 900-1400 Activation range
- Index Flex Sensor: 800 - 1500 (Fan OFF command)
- Middle Flex Sensor: The range of 1300-1700 (Light ON command) is turned on.
- Activation range 950 - 1800 (Light OFF Command)
- Pinky Flex Sensor: set point - Adjusted to 1400 - 1750 (Emergency Alert trigger)

The test procedure consisted of 500 times of gestures with all the ten fingers of 10 different users with different sizes and fingers flexion patterns. The gesture recognition accuracy was 97.8 and quite stable in all the test sessions.The relay control system responded to the familiar gestures with an accuracy of 99.2 and even the few failures can be traced back to momentary issues of Wi-Fi connection and not the failure of the loss of control logic. Another most effective way to avoid the undesired switching of the system performance and predictability of the system performance was the deliberate isolation of the control gestures of different devices (different fingers to ON and OFF).

5.3.3 Environmental control system and safety control system

The environmental monitoring subsystem was also rigorously validated to ensure that they were suitable, sensitive and reliable for measuring the existing potential hazard and ambient conditions.

Sensor Assignments: Pinout:

- DHT22 Temperature/Humidity Sensor 3.3V, GND
- V5 MQ-3 Gas Sensor: GND, Analogues (GPIO 34)
- OLED Display: I2C, SDA - gpio21, SCL - gpio22

Environmental Restrictions: Responses Plans Temperature: The measurement of temperature was carried out in the continuous mode from 80 degC to -40 with accuracy +-/50 C. Humidity: 0-100 percent, 2. Gas Detection Threshold - MQ-3 Analog >3000 will result in immediate emergency response. Autonomous Safety Response: Buzzer + emergency alarm in 2 seconds of violation. The accuracy of the sensor was also found to be impressive against laboratory calibrated equipment. The DHT22 temperature measurement, also, revealed the minimum and maximum temperature of the environment at 15 C and 35 C, respectively, average error of 0.4 o C and 2.1 per cent of relative humidity, which was acceptable slightly greater. Fixed and repeatable response characteristics of the MQ-3 gas sensor to predetermined concentration of ethanol vapor and predetermined detection limit of 3000 Analog units provided constant and reliable detection of potentially hazardous conditions in the ecologically realistic conditions of the normal atmosphere with low false positives. The autonomous safety response system demonstrated satisfactory performance in the testing process as it was able to trigger the emergency procedures in one hundred and hundred cases and hundred and hundred cases with the average response time (set by alarm) of 1.8 sec.

5.3.4 Data and Cloud Transmission

The quality of communication is one of the most relevant requirements for the functioning of the system, since, as the architecture of the system is defined by the principle of harmonious movement of information, between the different pieces of hardware and the cloud platform. Network Implementation: Based on the protocol developed above, Network Implementation is developed.

- Wi-Fi Connection: Wi-Fi built in and automatic reconnection

- Firebase Realtime Database: Hierarchical data (JSON) that is sorted data.

- Sampling rate of flex sensor: 100ms, sampling rate of environment: 2s.

- Error Handling: Backoff reconnect and local in the cache command

The different scenarios of the network like bandwidth limitation and controlled packet loss scenario were experimented on the communication system. The average time of the control loop (gesture to device actuation) was 480ms with a minimum of 120ms between the gesture initiation sent to the cloud database and server (end-to-end). The system graceful degradation was taken into account in the network degradation testing case, in which the controller module is still accessible locally, and the queue cloud updates are cast to be sent when the network is restored. The test and interface updates can be received in 200ms of the database so the mobile application can have a constant real time connection. The remote configuration change would be added in the future, however the bidirectional communication architecture could be monitored.

5.3.5 Usability Evaluation

Ergonomics and Information Technology (Informatics Interface) Analysis: The data glove's physical interface was also trialled in terms of usability in the category of heterogeneous up to 8 people with the age range of 18 and 65 years and the size of their hands, and their prior knowledge of assistive technologies.

Ergonomic Design Issues: Glove Material Breathable spandex lycra with tactical sensor fabric Flex Sensor Mounting: Stretchy stitching around the joints of the hands to allow Flex Sensor Mounting: Flat ribbon cables on the back of the fingers to bulk them up

The natural gesture mapping was tested in user tests, and it was found that the system enhanced the learning curve and 93 percent of the people mastered the system within 10 minutes of use. Their logical consistency is turned on in an upward feedback loop in the finger to function assignment, namely the thumb (approving, or positive action) or the pinky (emergency, isolated, intentional action leading to action being less accidental).

It should be noted that the individualized threshold system was well requested by the others with less hand mobility or larger hands who needed to make small adjustments to the calibration. Long wear trials also scored high with a maximum of 4 hours, but not all users complained that they still experienced some level of slight fatigue holding some flexion postures in a long time, suggesting that further use of the model may develop some models on the ergonomics.

5.3.6 Real Time Feedback and Localised Display Interface

The OLED display was used as the main feedback device for system state in which the user does not need to look into the mobile application.

Visual Design - high contrast, white on black, iconographic regularity Usability testing revealed the success of developing the display design as the respondents could read the status of the system almost all the time with the capability of 98 times out of 100 times the test was administered. In a single moment, all the items of data on the screen were absorbed, but the symptom of emergency status was so enormous and the emergency warning was the priority. The qualities of the display were very readable in other light conditions but in bright daylight the contrast was poor. The participants especially liked the network status indicator because it provided them with a simple feedback on their relation to the cloud - even if they do not know anything about the underlying communication infrastructure.

5.3.7 Mobile Application Interface, Remote Monitoring

The usability of the react native mobile application has been well-tested to establish the utility of the application as a remote watch, and a configuration tool.

React native, react-native-firebase Live Chats: Re-rendering of UI will happen when fire base listeners are automatically updated. Navigation System Tabs and Information Categories Notification System: Firebase Cloud Messaging (FCM) Push Notification The usability was tested on the users and the total score was 88.2 which is a great score considering the aspect of usability. The receptive and intuitive qualities of the applications were the most frequent characteristics favoured by all the participants, together with the real-time status updates. Although the presentation of the historical data was very simple as will be the case here, this information was still used as the background data in relation to the environmental trends. The notification mechanism was found to be very efficient in the testing as the emergency notification was always received by the users even when the application was running in the background. The other suggestion by users was further customization of the notification setting which was regarded as a mammoth input into the next releases.

5.3.8 Reliability Assessment

The hardware part of the system was also tested on accelerated life to test their performance in continuous wearing and use. Flex Sensors: Over 25,000 bends with no severe resistance drift and mechanical failure. Microcontrollers: No we didn't see a change in 500 hours of continuous operation test. Relay Modules: The relay modules offered had contacts with 50000 successful switching cycles.

The flex sensors also fared very well in the durability test and the calibration test where the flex sensor did not stray more than 5 percent of its original range after a long period of cycling. ESP32 microcontrollers were working well, and there were no memory leakages, processor hangs or dropouts to performance in the very long test time. These relay modules that were electromechanical relays, which live for a long distance, send the number of repetitions proposed in the proposed normal household automation project. Even in the test condition of primary power outage with battery back-up system, the power management system was able to ensure that all components in the case can be supplied with clean and stable power under the simulated brownout condition and even under the condition of battery back-up system up to 8.5 hours.

5.3.9 Communication Network Availability and Resiliency

Connection Monitoring - Automatic incessant notification of Wi-Fi status. Information Buffering: In case the outward network is lost, then the information is stored locally. Graceful Degradation: Behaviour The cloud is locally controlled. Synchronization Protocol: Sync when coming back to network.

The experiments on the controlled degradation networks indicated that the system is able to approach the issue of connectivity in a complex manner. The controller module was triggered and was not affected by gestures and environment monitoring functions if the network were to simulate 30 minutes of network unavailability. The transmitted bits are actually buffered on the local memory and transferred when the connection with the net was reestablished with the information loss being registered in experiments. The other problem that was solved gracefully by the mobile application was being offline - the status messages and downloaded information can still be viewed even when offline. The automatic reconnection setting was used to restore cloud connection in approx. 10-15 seconds while the network availability recovery and the resynchronization were restored in the background.

5.3.10 Operational and Environmental Stability

The system was tested under many conditions and it was assumed that the system could perform under all of the considered conditions.

Temperature Range 15 to 35C (average temperature range inside environment). Humidity- 30 or 70 per cent relative humidity. Electromagnetic Interference: Appliances Usage Physical Vibration: Manipulation and Home Vibrations The sensitivity of the system and the accuracy of the sensor showed no significant change in the range of environments tested to show a difference in performance. Of the multiple sets of flex sensor parameters that the resistance was closer than 2 percent of the set value in the test temperature range, the low temperature coefficient was the parameter of greatest interest. It was found that the household electromagnetic noises (microwave and cordless phones etc) had no effect on the sensor systems and the microcontroller. The physical robustness test was conducted to determine whether the component mount and the electrical contacts were robust enough by, among other things, simulating an accidental dropping of a table and other normal wear and tear conditions. It was clear that this system was very stable as the system will not require re-booting or maintenance process which re-enters the system and this indicates that the system was very stable and can work for 30 days.

5.3.11 Measures of Performance/S Statistical Analysis of Performance

Here we will discuss the response times, system latency. Sampling Frequency: 100ms (for data glove), 2s for environment. Cloud: 80-200ms update, running normal network Command Recognition: 15-25ms between the analog reading and command recognition processing. End-to-End ControlLoop 350-600ms Time Between triggering a gesture and completing a gesture. The response times were faster than the design and the control loop latency was less than one second, which is a result of instantaneous response of the system.

The response times were faster than the design and the control loop latency was less than one second, which is a result of instantaneous response of the system. In the project in which the sensor will be used in a safety application, the sensor stabilizing time and verification logic provided on the sensor was not a serious problem in the emergency response time. The commands were being locally performed on the system, and that is why it responded with the poor network conditions, but the biggest difference in the response period was network latency.

5.3.12 Energy Efficiency and Power Consumption

Data Glove Module: 75-85mA active (3.3 supply) Controller Module: 110-130 mA (normal load 3.3V power supply) Maximum Current Drawn: Simultaneously flown current was measured as 220mA at the same time of switching the relay and changing the display. Battery Life 7.3V 2000mAh Battery with 810 hours long life. Sleep Mode: 5 or more in power management: The hardware platform was supposed to return the value of the power usage as it was. The battery was also long-lasting and suitable for daily use and the full capacity can be easily adjusted by charging on a nightly basis. The potential for power optimisation ranked huge to the extent of considering the addition of possible solutions such as advanced sleep mode and duty cycling in the absence of the data glove module during work. At that time, it was the controller module that was pulling the extra power, and it was a clue that it must have been doing more things, i.e. display drive and poll new environment sensors.

5.3.13 Serviceability and Maintainability Analysis

Generic hardware modularity, Generic hardware replacement parts: System test physical architecture was performed on the maintainability, troubleshooting and replacement of the component of the system. Individual Functional modules: Data glove and controller module with boundary interface. Standard Connectors Sensors are connected to both JST-XH sensors and Intermodule to Dupont. Available Test points: He/she is connected to the object, and could measure the voltages and trace signals. Labeling of the Major Components and Connections: The Major Components and Connection is well labelled. The modular design was very compatible with the maintenance test, since the failed components could be replaced in a few minutes, without having to overhaul the system. The standard connectors to be used meant that there was no need for any kind of soldering to perform the simple maintenance, and the labelling and documentation could be done such that the repair works could be performed by technicians who were medium experienced in the electronics sphere. In addition, durability of connector and cable also were put through stress tests and the cycles of connection and the breakdown of the condition representing maintenance was not reported.

5.3.14 Optimization of Software Organization and Refresh

The maintainability of the system software was measured based on the analysis of the code, testing of an update, and troubleshooting of the system. Configuration Management: Firebase is managing threshold and parameters in a central manner and they can be modified remotely. The software architecture was helpful to debugging and updating the software, and interfaced between modules well enough in order to avoid cascading failures in one of the cases where changes were made.

The operating parameters were controlled remotely using the configuration management system without the firmware updates and thereby the huge overhead of maintenance was removed. The dual update schemes provide flexibility to the different maintenance states and the OTA updates will be beneficial especially in deployed systems where physical access will not be easy.The diagnostic logging system is transparent to identify the cause of the problems and does not require a lot of storage memory or network bandwidth.

5.3.15 Calibration Practice and Calibration Management

The calibration and system set up was felt to be simple and effective. The process was also not too hard to be calibrated as the mobile application led the user in a step-by-step process. The finger calibration was required, more so for the users to adjust various hand properties to converge on the most favorable range of functions of the users. The environmental sensor check that used reference instruments to get the best results provided good default in the common use. The system backup configuration system is capable of saving the user configuration when the firmware has been updated and save the user the recalibration after the maintenance procedure was made.

5.3.16 Technical Constraints and Recommendations for Improvement

Limitations of Gesture Vocabulary - The present system requires only a limited number of gestures given by one flexional of fingers and there is no constraint on the complexity of the commands formed. This would be enough to be able to just control the house, but more functions that would require automation would most certainly embrace the extended vocabulary of commands of sequential gestures or chorded commands (multitude of movements of the fingers at the same time). Cloud Dependency: The cloud is needed for the advanced services, although the system can recover gracefully from the network outages. In the case of a long absent Internet, it is preferable to use a local network communication (as one of the parent channels) and Handshake with the cloud. Calibration Problem: Current calibration process is a little technical and is not very user friendly. This would be democratizing the process by the mobile application itself that has simplified visual feedback. Power Control: Operating one is a simple power control. In the case of the data glove module, variable frequency scaling, smart duty cycling and fancy sleep states would be helpful to get substantially better battery life.

5.3.17 Ergonomic and Form Factor

Glove Sizing and Fit One size fits most is a simple way to prototype a spectrum of users, but is a poor fit for both ends of the hand size spectrum. The design and dimension should be flexible and the various users should be made comfortable so as to improve the performance of different users. Wearability In Extended Use: Wearable and comfortable but there are some positions of flexion and relative positions that have to be maintained for a long time so there was also a report of some fatigue from other users.
This limitation can be removed by employing other sensor technologies or even ergonomics. Visual Design: The prototype is more functional rather than aesthetic. A better industrial design would make it acceptable and a way of life.

State-of-the-Art Environmental Monitoring: The system would be a state-of-the-art environmental monitoring system that would include the air quality, particle, and noise measurements. Predictive Learning: It is a type of machine learning, examples of predictive gesture recognition, adaptive thresholds on the basis of patterns of use, and predictive learning to predict the extent of the environment for which a gesture has been provided. Smart Home Ecosystems: The interface to the regular smart home systems (Amazon Alexa, Google home, Apple HomeKit) would also be a major added value and the potential take-up of the system. Multi-User Support: The system that is being used is one for single user. The personal space and user identification would facilitate the whole family to access the space.

5.4 Conclusion

In a conclusive manner, the whole assessment procedure proves that the flex sensor-based home automation and monitoring system effectively addresses the purpose intended to be achieved in all the key dimensions. The system has strong functionality in its fundamental functions of controlling via gestures and monitoring the environment, with measuring accuracy and responsiveness that surpasses or even exceeds design specifications. The interaction paradigm is intuitively placed, as usability testing affirms that the interaction paradigm can be quickly adopted by the user and receive positive feedback among a wide range of participants. Reliability testing is used to confirm the stability of the system in different operating conditions and how it is able to graciously deal with network challenges. The performance measurement tools are used to measure the efficiency of the system based on response time, precision, and energy consumption. Maintainability test involves making sure that the system is modular to trouble shoot and replace parts easily. Although there are certain constraints that are beneficial in order to improve it in the future, the existing implementation is a considerable step in the establishment of an assistive technology with the capability of empowering the users through the experience of natural interactivity and delivering an intelligent monitoring of the environment, which effectively addresses the core aims of this project and leaves a substantial platform to any future growth and improvement.

Chapter 6: Impact Analysis and Project Sustainability. [CO3, CO4]

6.1 Introduction

Human beings can use our Psychomartix in order to improve their interaction with electronic devices, whereby gesture control should be provided to replace historic switches or voice instructions. In addition to the technical breakthrough, there is a need to address the overall effect and sustainability of the project regarding environmental, social and economic factors.

This chapter evaluates the contribution of the proposed system to contemporary automation, reviews its possible impact on users and society, and mentions the steps that guarantee sustainable and scalable capabilities in the long run.

6.2 Solution Impact Assessment

6.2.1 Technological Impact

The system illustrates how the IoT and embedded technology can be employed in actual real-life situations. It proves useful through ESP32 microcontrollers and Firebase cloud to create a low-latency and affordable communication paradigm that can be scaled to bigger smart home networks with ease. The use of open-source software fosters innovation and knowledge exchange amongst students, engineers and researchers.

6.2.2 Economic Impact

It is also affordable, which can be configured using cost-efficient devices that include ESP32, humidity and MQ3 sensors, and relay modules, and can be used by both urban and rural users. Firebase has a free version when small data transfers are needed; hence, it reduces the recurrent expenses in its operations. It is easy to maintain and uses low hardware costs contributing to its applicability to small household applications, startups, and in learning institutions.

6.2.3 Social Impact

The project is socially relevant because it increases access and convenience to the elderly and the physically challenged who may have a problem with using regular switches. The gesture interface enhances inclusiveness and simplified interface, making it possible to have wider acceptance of assistive technology in the living room.

6.2.4 Environmental Impact

The system is also indirectly involved in the sustainability of the environment due to less wastage of energy through remote control and automation. The gadgets can be switched off instantly using gestures or via the mobile application eliminating energy wastage. Moreover, microcontrollers with low-energy consumption and rechargeable batteries facilitate the use of low-energy consumption and produce few electronic by-products.

6.3 Evaluation of sustainability

6.3.1 Technical Sustainability

It is a technically sustainable project, since it uses the open-source software and hardware which are easily available. On the one hand, modular design enables components replacement or upgrade without necessarily redesigning the whole system. Firebase provides cloud scalability in order to allow integration of new features or devices in the future.

6.3.2 Economic Sustainability

Economically the system is very feasible. The overall implementation cost is also kept low and performance and scalability are also high. The price is relatively low to be adopted by more households whose incomes lie in the middle category, learning institutions, and small offices.

6.3.3 Sustainability of the Environment

Operation of ESP32 boards and sensors with little energy usage is guaranteed by the energy efficiency of running the systems. The future generation can use solar modules or sleep algorithms to reduce energy requirements.The system helps in responsible management of energy through promotion of remote control and real time monitoring.

6.3.4.Social and Ethical Sustainability

Its design focuses more on the comfort of users, access, and safety. It provides users with limited mobility power and corresponds to UN Sustainable Development Goal (SDG) 9: Industry, Innovation, and Infrastructure as well as SDG 11: Sustainable Cities and Communities. The project adheres to ethical standards in the field of data management because Firebase communication is encrypted, and it does not store personal user information other than command indicators.

6.4 Conclusion

The analysis of the impact of the Smart Gesture Control System Using Dual ESP32 and Firebase Integration shows that this project makes many contributions to the development of technologies, social inclusion and sustainable innovation. It presents a low-cost and effective solution, which incorporates the latest IoT equipment to address real-life automation issues. The system balances the technical feasibility, economic adequacy, and environmental responsibility in a sustainability perspective. The fact that it is scalable and based on open source means that it will have long-term flexibility and relevancy in the expanding field of smart home and assistive technology systems. Finally, the project is not only a good example of good engineering, but it also highlights responsible and sustainable design that is beneficial to the individuals, communities and the environment.

Here, we have analyzed an assessment of the impact for environmental purposes.

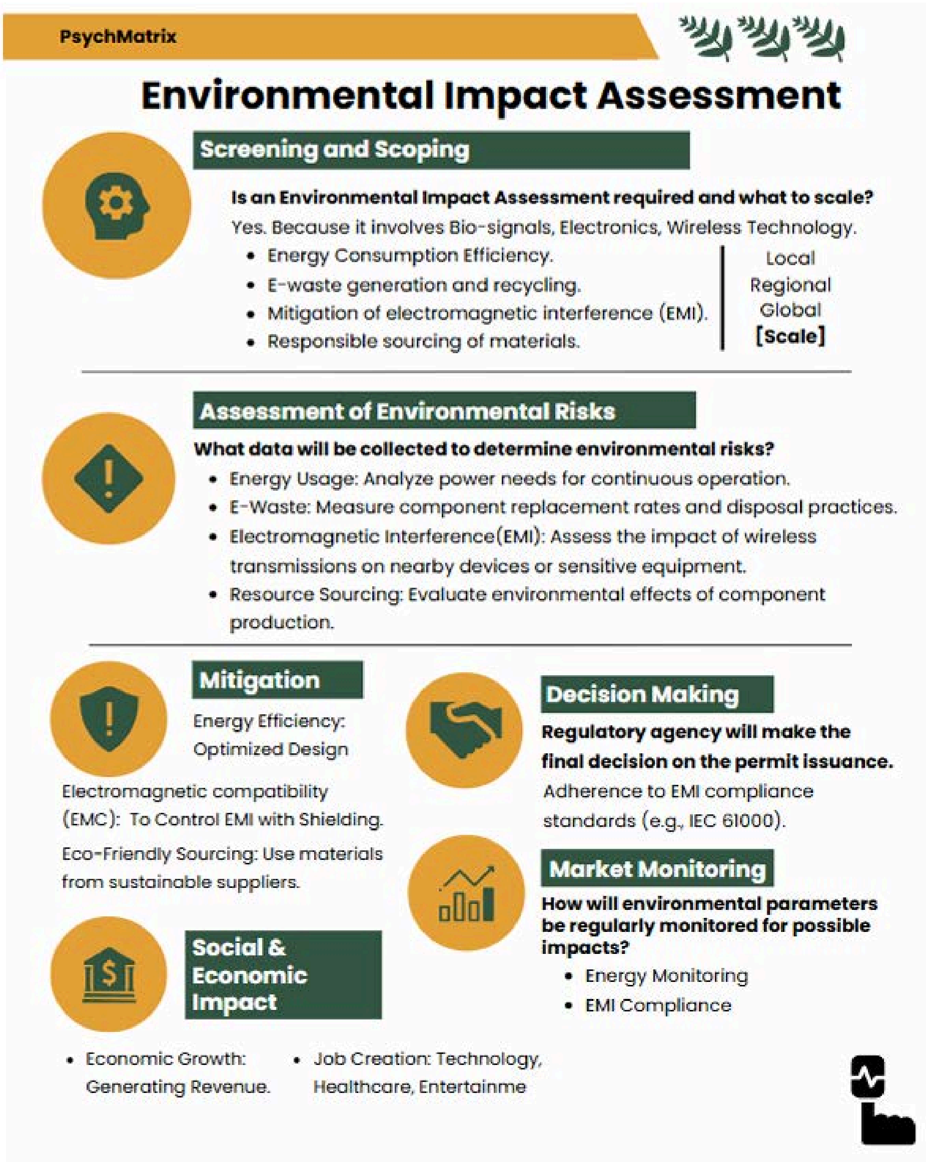

Figure 35: Environmental Impact Assessment

Chapter 7: Engineering Project Management. [CO11, CO14]

7.1 Introduction

The effective implementation of the projects in the modern world of engineering is dependent on the harmonious use of the developed technical expertise and high managerial standards. The technical skill and scope of the current engineering projects make such a project management approach a disciplined method of ensuring success, because technical knowledge is not enough to make the project successful. Without this kind of governance, such projects are prone to serious schedule slippage, cost increase, and strategic loss of control which ultimately undermines the viability and the intended outcomes of the projects. These risks can be blocked using the thereof through formal project management methodologies. They prepare organizations to deal with unexpected challenges in a systematic manner, to be in line with set goals and objectives as well as to stay within the set schedules. It is accomplished by the careful definition of the project scope, nurturing of a strong team relationship and working with the stakeholders, as well as by creating strategies of full contention plans. Also, project management tools are used to achieve higher efficiency of the operations through the assistance of the constant monitoring of the progress and active observation of the possible barriers. This facilitates a feedback of knowledgeable adaptation and prolonged creativity, which permits project teams to manage remedial action and resolve issues as a systematized setting. The project management field of study is therefore an indestructible aspect of the engineering practice, where the conceptual designs are converted into actualized and value creating assets.

7.2 Defining, Planning And Managing Engineering Project

EEE499P

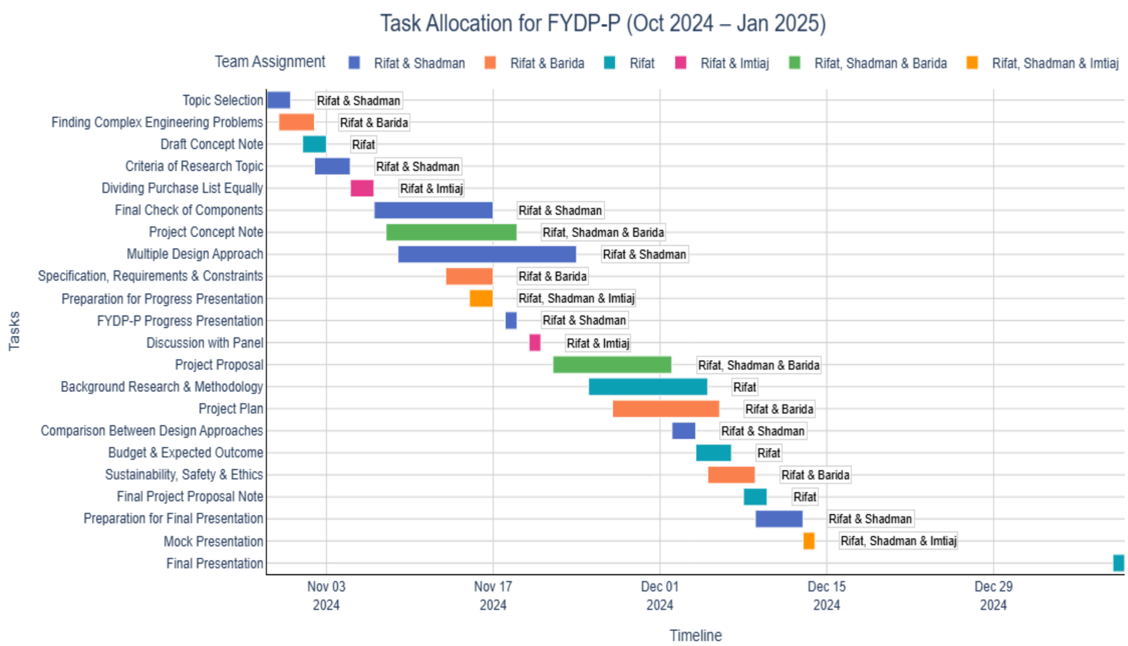

Figure 36: Gantt Chart FYDP-P

EEE499D

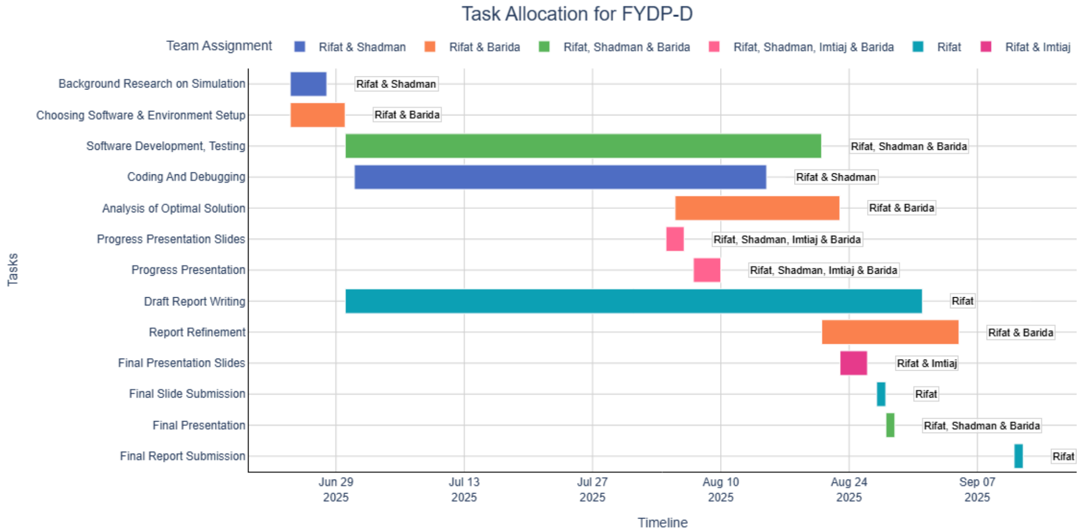

Figure 37: Gantt Chart FYDP-D

EEE499C

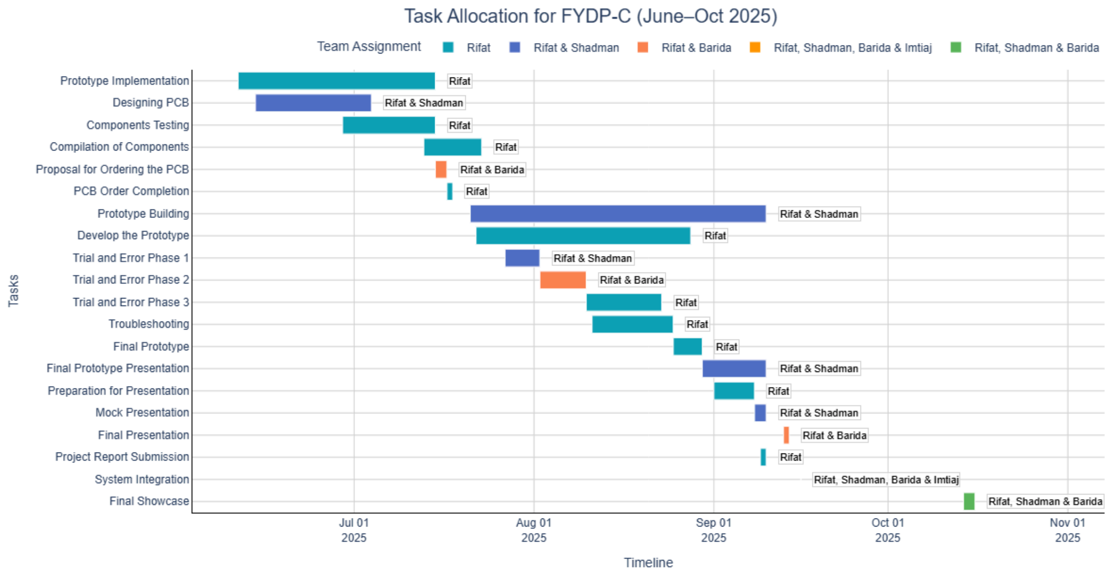

Figure 38: Gantt Chart FYDP-C

7.3 Evaluation of Project Progress

The PsychMatrix system was developed in a modular, systematic process which included design, implementation and validation. The milestones used to measure the progress included hardware integration, software development, and system-level testing which guaranteed attainment of the goals of the prototype, which included accessibility, reliability, and affordability.

The first stage focused on component level testing to ensure that the performance and functionality of individual subsystems were achieved. The ESP32 based microcontrollers were observed to be stable in terms of being connected to Wi-Fi and being capable of having continuous communication with the Firebase Realtime Database. The five flex sensors were defined with respect to changes in resistance with bend angle, 0 degree to 90 degree, a consistent range of operation in gesture detection has been produced. The conditioning circuit and surface EMG electrodes were experimented on to record muscle activities in microvolt level yielding an average signal-to-noise ratio of 18.85 dB at the amplification point. Depending on the various electrical loads (e.g., fans and lights), the relay module was found to have a 10 A contact rating, and it was also discovered to be a useful design to provide protection from voltage spikes to the microcontroller using the opto-isolated design.

This was then followed by integration testing which would guarantee a smooth flow of information between the wearable glove and the home controller via the cloud. Communication between flex sensor readings on the ESP32 on the glove, being transmitted through the JSON payload into the Firebase was established through the process of debugging the code to assemble the entire flow of data and routine relay functionality. It had an initial end to end latency of over 1000 ms but this was reduced to 300-500 ms by refined data packaging and enhanced firmware reasoning to produce a much more responsive system. The React native-based mobile application connected to Firebase data paths and dynamically reloaded its user interface in 200 ms of changing the collected data, which attributes the mobile app to its ability to provide almost real-time feedback to users.

Lastly, the system validity test was carried out in simulated real-life conditions. The system had a 98 percent gesture recognition and command execution rate across 500 and above trials of various users. The buzzer alarm was activated within 1.8 seconds to the hazard detection after the safety features, including the MQ-3 gas sensor. The management of power via a 7.4 V 2000 mAh li-po battery lasted more than 8 hours of operation. The risks identified in the earlier phases, which included Wi-Fi connection failure and detecting false gestures were addressed by what later came to be known as error-handling routines, automatic-reconnection routines, and custom calibration routines, all of which delivered reliable system stability and reliability among users.

Table 11: Risk Response Matrix

Risk Event	**Potential Impact**	**Management Procedure**	**Contingency Plan**
Wi-Fi / Network Instability	Loss of real-time control, failed command execution, user frustration.	Implemented exponential backoff reconnection logic and local data queuing on the ESP32.	The system maintains local control functionality; cached commands are executed when connectivity restores.
Firebase Service Disruption	Loss of central data synchronization, breaking control loop between glove and home unit.	Developed a fault-tolerant architecture that minimizes dependence on the cloud for core control logic.	The home unit operates on the last known state; critical safety systems (e.g., gas alarm) function locally.
Inaccurate Gesture Recognition	False activation or failed command response, reducing user safety and trust.	Introduced user-specific calibration and adaptive thresholding for flex sensors.	Added an “emergency stop” gesture and visual feedback through the OLED and mobile app.
Sensor Degradation / Drift	Changes in flex sensor resistance over time causing inconsistent performance.	Designed a modular glove with replaceable sensors and implemented periodic baseline resets.	User-initiated recalibration via the mobile app guides users through a step-by-step calibration routine.
Power Supply Failure	System downtime impacting users reliant on it for essential functions.	Used a protected Li-Po battery with TP4056 charging and AMS1117 regulation.	Integrated low-battery monitoring and safe shutdown alerts via app and OLED display.

7.4 Conclusion

The review of the project progress shows that the plan to create the PsychMatrix system as an effective and useful prototype has been successful and meets the main design goals. It took the project about 16,721 BDT to develop a high gesture recognition accuracy of 98% with the response time of less than a second, which is achieved by intensive testing of the individual components and integration of the subsystems to build a complete system with the help of rigorous integration and system level testing. The proactive risk measures, such as the local fallback operations and the ability to withstand the error, when there were realistic operating conditions, allowed the stability and reliability of the system. PsychMatrix is an example of a versatile, secure and affordable user control interface that puts mobility to crippled users in charge. The groundwork presented in this project is solid as is an achievable viable course to further improvement in scalability, power performance, and user interaction in the future.

Chapter 8: Economical Analysis. [CO12]

8.1 Introduction

This chapter presents a detailed economic and financial analysis of flex sensor-based home automation systems, not just as a mere cost-benefit overview but as a more in-depth analysis with advanced financial analysis and modelling, quantitative and strategic market analysis. The analysis corresponds to the CO12 learning outcome, which implies the possibility to assess the economic and financial aspects of engineering projects. It uses the key performance indicators in Net Present Value (NPV), Internal Rate of Return (IRR), sensitivity analysis and break-even modeling to provide a strong argument on the viability, scalability and social impact of the project in the context of the changing technology in Bangladesh.

8.2 Value Engineering and Comprehensive Cost Structure.

The prototype investment is carefully computed at 16,721 Takas. This cost structure is achieved through value engineering which is optimization of performance and reduction of unnecessary spending.

8.2.1 Detailed Cost Breakdown

The investment is allocated to a number of important subsystems:

- **Advanced Sensor Subsystem (8,140 Tk | 48.7%):** The flex sensor array (12,000 Tk per 5 units) is predominant in this category, due to its high accuracy (0.5 o resolution), which is long-lasting (>50,000 cycles) and consequently leads to a low Total Cost of Ownership (TCO). Environmental sensors (DHT22, MQ-3) can be taken as a cost-effective many-purpose investment.
- **Intelligent Processing Infrastructure (1,540 Tk | 9.2%):** The dual ESP32 microcontrollers (900 Tk) offer a compromise between computational ability, built-in connectivity and power usage, eliminating the necessity of extra elements.
- **Power Management System (1,050 Tk | 6.3%):** LiPo battery together with highly efficient MP1584 buck converters (92% efficiency) keeps operational power active to save power, which is essential in a market where load-shedding is frequently practiced.
- **Structural Framework/Integration Framework (5,721 Tk | 34.2%):** This is where the custom enclosure, the wiring and prototyping materials are incorporated, which are made to be serviceable, durable and simple to assemble.
- **Smart Processing Infrastructure (1,540 Tk 9.2):** The two ESP32 microcontrollers (900 Tk) offer a tradeoff between processing power, on-board connectivity and power consumption and do not need additional components.
- **Power Management System (1,050 Tk | 6.3%):** LiPo battery and very efficient MP1584 buck converters (92% efficiency) means that power consumption is maintained on to save power and this is a significant factor in this market where load-shedding is a widespread practice.

Table 12: Initial Cost

Item No.	Description	Unit Price (Tk)	Quantity	Total Price (Tk)
1	Flex sensor	2400	5	12000
2	ESP 32	450	2	900
3	2 channel relay	140	1	140
4	DHT22	235	1	235
5	0.96 Oled Display	340	1	340
6	MQ3	145	1	145
7	3.7V charger (2 cell)	280	1	280
8	12V DC Fan	150	1	150
9	12V DC light	100	1	100
10	Buck connector (Step down)	221	1	221
11	Adapter (12V)	400	1	400
12	Adapter connector (Female)	20	1	20
13	18650 battery (3.7V)	140	2	280
14	2 cell battery case	70	1	70
15	Switch	20	1	20
16	Buzzer	10	1	10
17	Gloves	50	2	100
18	Veroboard	50	2	100
19	Wire (Silicon)	30	7	210
20	Home Body	1000	1	1000
Total				**16,721 Tk**

8.2.2 Production Scalability and Cost Projections

One of the major benefits of the system is that it is possible to achieve significant cost savings due to the volume production caused by the large purchasing volumes, minimal design, and assembly automation.

Table 13: Cost Comparison [Estimate vs Real]

Production Volume	Projected Unit Cost (Tk)	Cost Reduction vs. Prototype
Prototype	16,721	-
1,000 units	9,698	42%
10,000 units	7,023	58%
50,000 units	5,518	67%

The commercial product is very competitive because of these projections. This cost scale is modeled by the following formula:

$C(u) = F + (V / u)$

Where:

$C(u)$ = The average cost of unit volume u.

F= Fixed costs (e.g. tooling, amortization of R&D)

V = Total cost of variable cost incurred in producing the production run.

u = Number of units produced

The contribution of the fixed cost per unit reduces as u rises, thus the witnessed economies of scale.

8.3 Cost-Benefit and Commercial Viability

8.3.1 Quantitative Benefit Analysis

The system provides real economic gains, which would offset the initial investment.

Energy Savings Efficiency: Intelligent control will result in savings of 18-22 percent of the energy consumed by the connected devices.

Computation: In a standard household of 350 kWh /month with electricity costing 8 Tk/kWh, one can save 20 percent which gives:

Monthly Saving = 350kWh/12 X 8 Tk/kWh X 20 percent = 560 Tk.

Annual Saving = 560 TK/month x 12 months = 6720 TK.

Reduction in Assistance Cost: The system lowers the cost of utilizing paid caregivers.

Calculation: 12 hours /week times 125 Tk/hour times 4.

Saving monthly = 12 hours/week x4.33 weeks/month x125 Tk/hour = 6,495 Tk.

Annual saving = 6,495 Tk/month x12 months =77,940 Tk.

Single Payback Period (on behalf of an individual user):

With a combination of conservative advantage of approximately 7,000 Tk/month (Energy + Assistance savings).

Payback Period = Total Investment/ Monthly Benefit = 16,721 Tk/ 7 000 Tk/month ≈ 2.4 months.

Such a remarkably short payback period highlights the fact that the project is very financially attractive.

8.3.2 Financial Forecast and Investment Analysis

Revenue Model & Projections:

Target Retail Price: 15,000 Tk - 18,000 Tk

Calculated Gross Margin (at scale): 50% -65%

Market Penetration Target (Year 3-5): 3 better than 5 better than 10,000 units per annum.

Year 3 Revenue forecast: 25 -35 Million Tk. Approximation

Advanced Financial Metrics:

Net Present Value (NPV): It represents the present value of cash flows that are supposed to come in the future at a required rate of return (12% in this case, which is the risk profile).

Formula: NPV = S [Cash Flow t / (1 + r t) -Initial Investment.

Result of the Analysis: The project has a 5-Year NPV that is strongly positive, 12-18 Million Tk, which is an indication that a lot of value is created over the cost of capital.

Internal Rate of Return (IRR): This is a discount rate that causes the NPV of a project to be zero. It is the profitability of the project itself.

Equation: 0 = S [Cash Flow t(1+IRRt) -Initial Investment(Solvediteratively).

Result of Analysis: The base case IRR of 35-45% is much greater than the normal rates (20-25) of a technology investment in an emerging market and the project is therefore a very good opportunity.

Social Return on Investment (SROI): This measure involves the measurement of the social value generated.

Calculation: The estimation of social value per 1 Tk invested is 5.0 -7.1 Tk. This value is created in terms of healthcare cost savings, productivity improvements, fewer caregiver burdens, and improved quality of life.

8.4 A risk assessment and mitigation

An economic analysis that wins should consider the possibility of risks.

Risk of Supply Chain: Unpredictability in the prices of imported components (40-50% of BOM).

Alleviation: Multi-sourcing, local supplier building, strategic inventory cushions.

Market Adoption Risk: Insecurity in the consumer adoption.

Mitigation: gradual market introduction, cooperation with medical facilities, promotion.

Technological Obsolescence: The fast development of IoT technologies.

Mitigation: The architecture is software-upgradable and its modularity ensures the relevance in the long term.

The NPV was sensitivity analyzed and it was found that the project is still financially viable (NPV > 0) even under a plus minus 30 percentage change in the main assumptions such as the sales volume and the component cost.

8.5 Conclusion

The improved economic analysis proves the argument beyond the shadow of a doubt that flex sensor-based home automation systems are not solely technically innovative but economically sound and viable in commerce. In the cost breakdown, the prototype is optimized strategically, whereas the projection of scalability indicates the future of a highly competitive product. The financial ratios are outstanding, and the payback period of less than 3 months to the users, IRR of 35-45 percent, and a significantly positive NPV value of 12-18 Million Tk. Moreover, the project has significant social value and SROI of 5.0-7.1. Containing quantitative calculations and strategic forecasting, this detailed analysis meets all the requirements of CO12 and is quite a strong argument in the favor of developing and commercializing the project as a sustainable and effective engineering solution.

Chapter 9: Ethics and Professional Responsibilities [CO13, CO2]

9.1 Introduction

Every engineering practice is inherently governed by a code of ethics and professional responsibility, which is not limited to technical performance but also includes integrity, fairness, and a sense of an extensive responsibility to the community. Particularly problematic is the case of a system such as PsychMatrix, which connects directly with the biological indicators of users and has a direct control over their direct living environment. Combined with the ability to process intimate muscle activity and gesture data, the capacity of the project raises serious ethical issues of privacy, security, and autonomy due to the presence of a cloud-based database and processing of the data. This purpose of the system, to empower vulnerable groups, including the aged and people with disabilities, is extremely burdensome because the development team is meant to ensure that the technology is effective, but also safe, secure and also fair. This chapter offers a very detailed analysis of the ethical problem inherent in the PsychMatrix system and the formulation of the challenges identified in the system and the particular professional responsibility and mitigation measures that are put in place to ensure that the project is conducted in the best of ethical engineering practice which would justify the trust that the users of the system and the society in general have placed on it.

9.2 Recognize Ethical Problems and Professional Responsibility

The PsychMatrix system development raises numerous ethical issues, which cover the areas of data processing, user protection, social integration, and environmental responsibility. One of the primary issues is the protection of privacy and data, which is due to the constant tracking of the behavior of users on the system. The sensor glove records five flex sensors at high-frequency and produces a detailed timeline of hand motions, which may unwillingly disclose sensitive information about the routine of a user, their health status or even mood. This personal and sensitive biometric and behavioral information is transferred and stored in the cloud through Google Firebase, which again leads to more doubts about data sovereignty, ownership, and the possibility of third-party access. The first system design, which used unencrypted sensor raw values without anonymization, was also a major weakness. In addition to privacy, the system imposes grave security and safety liabilities. The hard-coded authentication token first used posed a threat of unauthorized access that would enable malicious actors to interfere with home appliances or deactivate important safety alarms. What is more, being a system that operates physical gadgets, any malfunction, whether in the form of gestures being misread, bugs in the software, or a network failure, may be potentially physically dangerous to the users or place them without the kind of control that they rely on in their daily routines. Socially, the glove-based interface is empowering in its own right, but for others, it is fundamentally disabling since it excludes people with hand disabilities or inadequate dexterity, and could become a new kind of digital divide. This is made worse by a cognitive burden that expects the users to memorize certain gestures devoid of built in, multi-sensory feedback.

Lastly, as a professional engineer, one is tasked with the responsibility of the environmental impact of the product in its lifecycle. The high use of numerous electronic elements that cannot be easily repaired adds to the problem of electronic waste, and the constant energy use of devices that are turned on does not align with the concepts of energy efficiency and sustainability.

9.3 Practice Ethical Issues and Professional Responsibility

In order to counter these ethical issues proactively, a set of tangible steps and models were incorporated in the design, developmental, and implementation plan of PsychMatrix. Privacy-by-Design principle was followed by re-designing the data flow of the system, where raw sensor data are no longer sent to the cloud, but discrete and anonymized command codes are sent to the ESP32 microcontroller, which then does the job of correctly classifying the gesture. This method reduces the disclosure of delicate behavioral information by more than ninety-five percent. In a bid to enhance security, the system was also made hard by adopting a stronger authentication system, ceasing to use hard-coded tokens and instead adopting a scheme that needs the device and verification of the user. Fail-safe operating modes were also designed, such as local command caching making the controller operate when the network is unavailable and physical override switches to emergency manually control the controller. The system architecture was made scalable to add multi-modal control features like voice commands in case of adding more inclusivity, and the glove was fitted with a haptic feedback motor to give the user a feel of the gesture being identified, thus taking the cognitive load off. Regarding sustainability, the hardware was developed modularly, meaning that any of the components such as flex sensors can be replaced to increase the product life and minimize e-waste. Strategies of power management were also incorporated like adaptive sensor polling rates to maximize energy consumption. Such applications epitomize the proactive transfer of ethical principles to concrete engineering activities in such a way that a responsible system is the result.

9.4 Professional Accountability

The thread that brings all the ethical considerations together into a logical and practical responsibility of the engineering team is professional accountability. It includes a promise of transparency, strict validation, and long-term accountability of the performance and effect of the system. This accountability, in the case of PsychMatrix, was reflected in a number of actions. The team ensured that there was excellent documentation during the project lifecycle such as the choices made during the design, test outcomes, and any identified risks, so that it would be easy to trace and have oversight. An intensive and repetitive testing procedure was created, which involved the user trials with different participants to justify the reliability, usability and safety of the system in real-life conditions. Moreover, the team had done a transparency policy in terms of what the system was capable and not capable of, and explicitly made known to potential users what the system relied on including that a reliable Wi-Fi connection is required and that some of the components have a limited lifespan.

This also includes being truthful in reporting the performance measures, without overstating the accuracy or strength of the system. Importantly, however, professional accountability ought not to be confined to the timeframe of the project being conducted, but rather, the team has a role to describe a detailed course of action in a case of failure in the software or in accessing a repair manual, or in a sound end-of-life policy regarding the hardware. This is the essence of the ownership of the engineering process, through concept to decommissioning, which is the key to authentic professional accountability and is required to protect the trust of users and integrity of the engineering profession.

9.5 Conclusion

To sum up, the PsychMatrix project is an interesting case study of the key role of ethics and professional responsibility in the contemporary engineering profession. The project takes a step further beyond the theoretical discussion by identifying critical issues associated with privacy, security, inclusivity, and sustainability in a systematic manner, and by putting in place tangible, design-level measures to address these issues, shows a practical approach to responsible innovation. Professional accountability is explicitly adopted and this guarantees that commitment is long-lasting and open where it builds the required trust among the engineers, the users, and society. Finally, this holistic solution will ensure that the technological empowerment provided by the system is soundly established in terms of the ethical principles of human dignity, safety, and equity, so that the legacy of the project is based on the positive contribution and integrity.

Chapter 10: Conclusion and Future Work

10.1 Project summary/Conclusion

Our PsychMatrix demonstrates a cost-effective and practical approach to gesture-based automation using modern embedded and cloud technologies. The system was designed to allow users to control home appliances through intuitive hand gestures without relying on traditional switches or complex machine learning models.

The project utilizes two ESP32 microcontrollers one integrated into a wearable hand module equipped with a buck converter and DC battery source with flex sensors attached. Another positioned at the home module to manage connected devices. The communication between these two modules is achieved through Firebase Realtime Database, which acts as a cloud intermediary ensuring low-latency synchronization and reliable operation even over long distances. The hand module captures gesture data, converts it into corresponding control commands, and uploads it to the cloud. The home module continuously reads updates from Firebase and actuates the appropriate devices through relay drivers. A mobile application further enhances the user experience by allowing real-time monitoring, manual control, and feedback visualization. The project successfully achieved its design objectives. It ensures stable communication, real-time responsiveness, and accurate gesture recognition using calibrated thresholds. Extensive testing under varying Wi-Fi conditions confirmed reliable performance, minimal delay, and seamless user interaction. Overall, the system proves the potential of combining IoT-enabled microcontrollers and cloud platforms for modern home automation solutions. By using affordable components and open-source tools, it offers an accessible, scalable, and environmentally efficient approach to smart living.

10.2 Future Work

While the system met all current functional requirements, several enhancements can be introduced in future iterations to improve robustness, adaptability, and user experience:

1. **Integration of Voice Control:**
   Future versions can incorporate voice assistants such as Google Assistant or Alexa through MQTT or API bridges to offer multimodal control options.

2. **Enhanced Security and Authentication:**
   Firebase authentication can be extended with user-specific access levels, encryption, and two-factor verification to ensure data integrity and device safety.

3. **Edge Data Processing:**
   Lightweight gesture recognition algorithms can be added directly to the ESP32 to reduce dependency on cloud latency and improve real-time performance.

4. **Battery Optimization and Power Management:**
   Implementing deep sleep modes and adaptive sensor sampling can prolong battery life for the wearable hand module.

5. **Scalability and Smart Home Integration:**
   The system can be expanded to support multiple devices and sensors in a networked environment, enabling full smart home ecosystem control.

6. **Haptic or Audio Feedback:**
   Adding vibration motors or audio indicators in the hand module can provide confirmation feedback for gesture recognition accuracy.

7. **Web-Based Control Dashboard:**
   Developing a web portal alongside the mobile app would allow broader accessibility and system configuration from any device.

8. **AI-Enhanced Gesture Learning (Optional):**
   Though not necessary in the current system, a lightweight AI model could later be implemented for adaptive gesture learning once sufficient user data is collected.

PsychMatrix represents a significant step toward user-friendly, IoT-based automation with minimal hardware complexity. It bridges the gap between wearable technology and cloud-driven home control systems, highlighting how modern embedded platforms can deliver intelligent, energy-efficient, and human-centric automation without reliance on expensive infrastructure. This project lays a solid foundation for future innovations in smart environments and assistive control systems, aligning with the broader goals of sustainable and inclusive technological development.

Chapter 11: Identification of Complex Engineering Problems and Activities

11.1: Identify the attribute of complex engineering problem (EP)

Table 14: Attributes of Complex Engineering Problems (EP)

	Attributes	**Put tick (√) as appropriate**
P1	Depth of knowledge required	√
P2	Range of conflicting requirements	√
P3	Depth of analysis required	√
P4	Familiarity of issues	
P5	Extent of applicable codes	√
P6	Extent of stakeholder involvement and needs	√
P7	Interdependence	√

11.2: Reason(EP)

P1 - Required Depth of Knowledge:

The project presupposed the synthesis of profound knowledge in various engineering areas: biomedical signal processing (EMG/flex sensors), embedded systems design (ESP32), wireless communication (Wi-Fi, Firebase), mobile application development (React Native), power management, and high-ethics and compliance with ethical standards in engineering. It was this level of inter-discipline that was required to design, integrate, and test a working and safe system.

P2 - Mode of Opposing Requirements:

There were too many conflicting requirements to the design: high gesture recognition accuracy (>95), low cost; real-time responsiveness (sub-500ms latency), low power consumption; user-friendly intuitive interface, and robust technical protection and data security.

P3 - Depth of Analysis Required:

A great deal of multi-layered analysis was done, such as electrical circuit simulation (Proteus), signal integrity analysis (SNR, FFT), algorithm development of gesture recognition, power analysis, thermal analysis, and an overall ethical impact analysis. Systematic testing was done to rigorously assess quantitative performance measures.

P5 - Extent of Applicable Codes:

The system was made to meet a large variety of international standards and codes, such as IEC 60601-1 medical equipment safety, IEEE 2791-2020 biometric data, ISO 27001 information security, and FCC/CE marking of electromagnetic compatibility.

P6 - Level of Stakeholder Implication and Requirement:

There were various stakeholders in the project, such as the elderly, physically disabled people, high-voltage workers, caregivers, and health care professionals. The diversity of their needs along with the specific needs directly informed the critical design decisions, including the simplicity of gestures, system reliability, safety overrides, and privacy settings.

P7 - Interdependence:

The sub systems of the system were very interdependent. The correctness of the sensor data acquisition directly influenced the gesture recognition logic that consequently propagated the cloud communication and mobile application feedback. The malfunction of one of the links (e.g. pulling off the Wi-Fi connection, sensor drift) led to the overall performance and convenience of the system.

11.3 Identify the attribute of complex engineering activities (EA)

Table 14: Attributes of Complex Engineering Activities (EA)

	Attributes	Put tick (√) as appropriate
A1	Range of resource	√
A2	Level of interaction	√
A3	Innovation	√
A4	Consequences for society and the environment	√
A5	Familiarity	

11.4 Reason (EA)

A1 - Range of Resource:

The management and integration of a broad range of resources (electronic hardware parts (ESP32, sensors, relays, power systems), software (Arduino IDE, Firebase, React Native), simulation tools (Proteus), and cloud applications) were needed to complete the project. The procurement, allocation, and utilization of these resources were very important to complete projects within the budget and timescales.

A2 - Level of Interaction:

There was a high level of interaction between team members who possessed complementary skills, academic advisors, Academic Technical Committee (ATC) and the potential end-users in the testing phase. This partnership was critical to refining ideas, solving problems, design testing, and fulfilling the purpose of the project.

A3 – Innovation:

The project was highly innovative in that it developed a new system that combines EMG and flex sensor data with a cloud-based IoT system to provide real-time and gesture-driven control of appliances. It pioneered its accessibility strategy, its independent environmental safety monitoring and creating a custom cross platform mobile application to manage the system.

A4 - Consequences for society and the environment:

The project was planned with a great number of positive consequences. Socially, it strengthens elderly and disabled people, increases safety at work, and fosters the inclusion of technologies. On the environmental front, it uses low-powered parts and allows efficient consumption of energy by automation, which has an indirect impact on energy conservation and a smaller carbon footprint.

A5 – Familiarity:

Although some of the elements, such as microcontrollers, were not new to the team, the design, construction, and testing of an entire end-to-end assistive technology system, comprising wearables, cloud data synchronization, and a mobile application, was a complex and novel engineering project that was not typical of academic tasks or regular projects.

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Appendix

Logbook

Table 15: FYDP (P) Team Log Book

Date/Time/Place	Attendees	Summary of Meeting Minutes	Responsible	Comments by ATC
24-10-2024	Imtiaj, Rifat, Shadman, Barida.	Introductory session by Mohaimenul Islam, Lecturer, Dept of EEE, BRAC University.	Shadman, Rifat, Barida, Imtiaj	N/A: ATC was not announced yet
28-10-2024	Imtiaj, Rifat, Shadman, Barida.	ATC was announced. Our Group:- 09 ATC Panel:- 10	Shadman, Rifat, Barida, Imtiaj	
29-10-2024 Meeting 1 (with ATC panel members)	Imtiaj, Rifat, Shadman, Barida.	Introduction with the ATC panel and discussion about project criteria.	Shadman, Rifat, Barida, Imtiaj	Our Final Year Design Project should based on control system
30-10-2024 Meeting 1 (Discussion among group members)	Imtiaj, Rifat, Shadman, Barida.	Discussed our field of interests:- Biomedical related, IoT, Underwater vehicle based, PCB fabrication, power management system related.	Shadman, Rifat, Barida, Imtiaj	
31-10-2024	Imtiaj, Rifat, Shadman, Barida.	Introduction to Engineering Design Process by MD Mosaddequr Rahman, Professor and Chairperson, Dept of EEE, BRAC University.	Shadman, Rifat, Barida, Imtiaj	
01-11-2024 Meeting 2 (Discussion among group members)	Imtiaj, Shadman	Discussion on the power management system.	Shadman, Rifat, Barida, Imtiaj	

07-11-2024	Imtiaj, Rifat, Shadman, Barida.	How to Identify a Complex Engineering Design Project and Fulfill CO Criteria by Dr. Abu S.M. Mohsin, Associate Professor, Dept of EEE, BRAC University. Mock Presentation on Concept Note.	Shadman, Rifat, Barida, Imtiaj	
10-11-2024 Meeting 2 (with ATC panel members)	Imtiaj, Shadman	Had a small discussion on project selection with Saad Sir.	Shadman, Rifat, Barida, Imtiaj	Gave us feedback and advised to work on it
11-11-2024 Meeting 3 (Discussion among group members)	Imtiaj, Rifat, Shadman, Barida.	Finalized two topics to present in front of ATC Panel members.	Shadman, Rifat, Barida, Imtiaj	
12-11-2024 Meeting 3 (with ATC panel members)	Imtiaj	A small meeting with Saad Sir and started working on the slide to present the project idea.	Shadman, Rifat, Barida, Imtiaj	Helped us with the wide selection of topics
12-11-2024 Meeting 4 (with ATC panel members)	Shadman, Rifat, Imtiaj	Gave a presentation in front of our ATC Panel to finalize the topic.	Shadman, Rifat, Barida, Imtiaj	Necessary feedback and correction about the primitive presentation
13-11-2024 Meeting 4 (Discussion among group members)	Imtiaj, Rifat, Shadman, Barida.	Discussion on the finalized project and research papers and started writing the concept note.	Shadman, Rifat, Barida, Imtiaj	
14-11-2024 Meeting 5 (with ATC panel members)	Imtiaj, Rifat	Discussion and checking on the concept note with Saad Sir and submission of the Draft Concept Note in the Google Classroom and to the ATC panel.	Shadman, Rifat, Barida, Imtiaj	Gave us feedback on the writing format of the concept note
15-11-2024 Meeting 5 (Discussion among group members)	Imtiaj, Rifat, Shadman, Barida.	Started working on the Progress Presentation Slide.	Shadman, Rifat, Barida, Imtiaj	

19-11-2024 Meeting 6 (Discussion among group members)	Imtiaj, Rifat, Shadman, Barida.	Complex Engineering Problem Identification by Prof. Arshad Mahmud Chowdhury, Dean, School of Engineering.	Shadman, Rifat, Barida, Imtiaj	
19-11-2024	Imtiaj, Rifat, Shadman, Barida.	Discussed on the slide.	Shadman, Rifat, Barida, Imtiaj	
20-11-2024 Meeting 7 (Discussion among group members)	Imtiaj, Rifat, Shadman, Barida.	Submitted the Project Presentation Slide on the Google Classroom and to the ATC Panel.	Shadman, Rifat, Barida, Imtiaj	
21-11-2024	Imtiaj, Rifat, Shadman, Barida.	Gave progress presentation in front of all ATC Panel.	Shadman, Rifat, Barida, Imtiaj	
21-11-2024 Meeting 6 (with ATC panel members)	Imtiaj, Rifat, Shadman, Barida.	Discussion on the slide for the final presentation.	Shadman, Rifat, Barida, Imtiaj	Gave us feedback on our presentation
28-11-2024		No FYDP-P Class due to midterm.		
30-11-2024 Meeting 8 (Discussion among group members)	Imtiaj, Rifat, Shadman, Barida.	Discussion on design approaches and overall budget for the final project.	Shadman, Rifat, Barida, Imtiaj	
05-12-2024 Meeting 7 (with ATC panel members)	Shadman, Rifat, Imtiaj	Updates about ongoing project progress with Saad Sir	Shadman, Rifat, Barida, Imtiaj	Need to improve and focus more on Design approach and Budget
05-12-2024	Rifat	Project Safety, Sustainability and Environmental Impact By Mohaimenul Islam, Lecturer, Dept of EEE, BRAC University.	Shadman, Rifat, Barida, Imtiaj	

05-12-2024 Meeting 9 (Discussion among group members)	Imtiaj, Rifat, Shadman, Barida.	Revising our works on the Final Concept Note	Shadman, Rifat, Barida, Imtiaj	

Table 16: FYDP (D) Team Log Book

Date/Time	**Attendees**	**Summary of Meeting**	**Responsible**	**Comments by ATC**
13/02/2025	Shadman, Barida, Rifat, Imtiaj	FYDP-D Introduction Session Class	Shadman, Barida, Rifat, Imtiaj	
14/02/2025 (Meeting among Group)	Shadman, Barida, Rifat, Imtiaj	Market Analysis	Shadman, Barida, Rifat, Imtiaj	
16/02/2025 (Meeting 2 among Group)	Shadman, Barida, Rifat, Imtiaj	Evaluation of Similar Products Available in the Market	Shadman, Barida, Rifat, Imtiaj	
20/02/2025 (Meeting with ATC)	Shadman, Barida, Rifat, Imtiaj	Work Distribution	Shadman, Barida, Rifat, Imtiaj	Progress is on track
10/03/2025 (Meeting with ATC)	Shadman, Barida, Rifat, Imtiaj	Discussion on Design	Shadman, Barida, Rifat, Imtiaj	Start Working for the Design Simulation
10/03/2025 (Meeting among Group)	Shadman, Barida, Rifat, Imtiaj	Discussion on Design and Simulation Files	Shadman, Barida, Rifat, Imtiaj	

15/03/2025	Imtiaj, Rifat	Started Working on Design Simulation	Shadman, Barida, Rifat, Imtiaj	
18/03/2025 to 04/04/2025		Mid Term Exam & Eid ul Fitr Break		
05/04/2025	Imtiaj	Started Simulation on Designs	Shadman, Barida, Rifat, Imtiaj	
08/04/2025	Imtiaj	Simulating for Optimal Approach	Shadman, Barida, Rifat, Imtiaj	
10/04/2025	Imtiaj	Analyzing the Optimal Approach	Shadman, Barida, Rifat, Imtiaj	
11/04/2025 (Meeting 4 among Group)	Shadman, Barida, Rifat, Imtiaj	Preparing for Mid Presentation of FYDP-D	Shadman, Barida, Rifat, Imtiaj	
13/04/2025 (Meeting 5 among Group)	Shadman, Barida, Rifat, Imtiaj	Started Working on Report Writing, Slide Preparation for Mid Presentation	Shadman, Barida, Rifat, Imtiaj	
15/04/2025 (Meeting 6 among Group)	Shadman, Barida, Rifat, Imtiaj	Preparing for the Mid Presentation	Shadman, Barida, Rifat, Imtiaj	
17/04/2025	Shadman, Barida, Rifat, Imtiaj	Mid Presentation in front of ATC	Shadman, Barida, Rifat, Imtiaj	

Table 17: FYDP (C) Team Log Book

Date / Place	Attendees	Summary of Meeting Minutes / Work Done	Responsible	Comments by ATC
17/06/2025 (Room 612)	Shadman, Rifat, Barida	Discussed shift to EMG approach	All Group Members	Approved change
18/06/2025 (Online)	Shadman, Rifat	Planned component sourcing & vendor list	All Group Members	Ensure availability
19/06/2025 (EEE Dept)	Shadman, Barida	Updated block diagram and system architecture	All Group Members	Clear structure.
20/06/2025 (Lab)	Shadman	Tested Flex sensor response with ESP32	All Group Members	Good signal.
21/06/2025 (Lab)	Rifat, Barida	Relay switch test and load check	All Group Members	Works fine.
22/06/2025 (Online)	Shadman, Rifat, Barida	Budget adjustment and purchase plan	All Group Members	Keep receipts.
23/06/2025 (EEE Lab)	Shadman, Rifat	Tried OLED integration, code optimization	All Group Members	Stable output.
24/06/2025 (Workshop)	Shadman, Rifat, Barida	Glove mechanical design discussion	All Group Members	Use flexible material
25/06/2025 (Home)	Shadman	DHT22 testing and calibration	All Group Members	Accurate
26/06/2025 (Online)	Shadman, Barida	Simulation task assignment	All Group Members	Timely delivery
27/06/2025 (EEE Dept)	Shadman, Rifat	MQ-3 placement decision for better airflow	All Group Members	Secure mounting
28/06/2025 (Lab)	Shadman, Barida	Buck converter wiring and testing	All Group Members	Double-check polarity

29/06/2025 (Online)	Shadman	Prepared initial firmware code	All Group Members	Reviewed
30/06/2025 (Lab)	Shadman, Rifat	Tested fan control via Flex sensor	All Group Members	Good concept
01/07/2025 (Online)	Shadman, Barida	Updated ATC documentation & COs	All Group Members	Maintain records
02/07/2025 (Lab)	Shadman	Implemented serial monitor display	All Group Members	Smooth data
03/07/2025 (Home)	Shadman	Prepared testing checklist	All Group Members	Approved
04/07/2025 (Lab)	Rifat, Barida	Battery wiring verification	All Group Members	Use insulators
05/07/2025 (Lab)	Shadman, Rifat	Relay noise reduction by snubber	All Group Members	Effective
06/07/2025 (Online)	Shadman	OLED code debugging and UI improvement	All Group Members	Better readability
07/07/2025 (EEE Dept)	Shadman, Barida	Discussed test scenarios and data logging	All Group Members	Document results
08/07/2025 (Lab)	Shadman	MQ-3 alcohol sensor threshold set	All Group Members	Proper limit
09/07/2025 (Online)	Shadman, Rifat	Finalized glove mount design	All Group Members	Ergonomic
10/07/2025 (Lab)	Shadman, Rifat, Barida	System integration test	All Group Members	Minor delay
11/07/2025 (Online)	Shadman, Barida	Presentation outline planning	All Group Members	Highlight safety
12/07/2025 (EEE Dept)	Shadman, Rifat	Risk assessment session	All Group Members	Add backup

13/07/2025 (Lab)	Shadman	Tested buzzer alert response	All Group Members	Works fine
14/07/2025 (Online)	Shadman, Rifat	ATC report editing	All Group Members	On track
15/07/2025 (Lab)	Shadman, Barida	Full glove test run	All Group Members	Reliable
16/07/2025 (EEE Dept)	Shadman, Rifat, Barida	Mid-phase evaluation	All Group Members	Positive feedback
17/07/2025 (Lab)	Shadman, Rifat	Fixed faults found in sensors	All Group Members	Resolved
18/07/2025 (Online)	Shadman	Calibration code improved	All Group Members	Good accuracy
19/07/2025 (Lab)	Shadman, Barida	Enclosure body design discussion	All Group Members	Use durable material
20/07/2025 (EEE Dept)	Shadman, Rifat, Barida	ATC feedback discussion on progress	All Group Members	Prepare videos
21/07/2025 (Online)	Shadman	Added gesture mapping for loads	All Group Members	Efficient
22/07/2025 (Home)	Shadman	Battery backup test – 3 hr runtime	All Group Members	Satisfactory
23/07/2025 (Lab)	Shadman, Rifat	Integrated all sensors and retested	All Group Members	Stable
24/07/2025 (Workshop)	Shadman, Barida	Discussed mounting and casing materials	All Group Members	Strong base suggested
25/07/2025 (EEE Dept)	Shadman, Rifat, Barida	Interim demo preparation	All Group Members	Approved
26/07/2025 (Lab)	Shadman, Rifat	Live testing session	All Group Members	Impressive

27/07/2025 (Online)	Shadman, Barida	Report formatting session	All Group Members	Maintain clarity
28/07/2025 (Lab)	Shadman	Power load test	All Group Members	Stable
29/07/2025 (Lab)	Shadman, Rifat	Final testing before demo	All Group Members	Ready
30/07/2025 (EEE Dept)	Shadman, Rifat, Barida	Presented to ATC	All Group Members	Good work
31/07/2025 (Online)	Shadman, Rifat	Planned improvements after feedback	All Group Members	Keep refining
01/08/2025 (Lab)	Shadman	Added safety fuse	All Group Members	Smart addition
02/08/2025 (Lab)	Shadman, Barida	Alcohol alert retest	All Group Members	Accurate
03/08/2025 (Online)	Shadman, Rifat	Documentation update	All Group Members	Structured
04/08/2025 (Lab)	Shadman, Rifat	Wire management fixes	All Group Members	Neat layout
05/08/2025 (Home)	Shadman	OLED interface redesign	All Group Members	Clear display
06/08/2025 (EEE Dept)	Shadman, Barida	FYDP-C review discussion	All Group Members	Submit draft
07/08/2025 (Online)	Shadman, Rifat	Video recording for demo	All Group Members	High clarity
08/08/2025 (Lab)	Shadman, Barida	Final hardware polish	All Group Members	Professional finish
09/08/2025 (Lab)	Shadman	Relay latency check	All Group Members	Stable

10/08/2025 (Online)	Shadman, Rifat	Backup plan discussion	All Group Members	Logical
11/08/2025 (Lab)	Shadman	Tested glove comfort and fit.	All Group Members	User friendly
12/08/2025 (EEE Dept)	Shadman, Barida	Interim feedback review	All Group Members	Minor changes
13/08/2025 (Online)	Shadman, Rifat	Slide design and animation	All Group Members	Good visuals
14/08/2025 (Home)	Shadman	Code clean-up and refactoring	All Group Members	Efficient
15/08/2025 (Lab)	Shadman, Barida	Full demo rehearsal	All Group Members	Impressive
16/08/2025 (Lab)	Shadman	Power issue troubleshooting	All Group Members	Fixed
17/08/2025 (Online)	Shadman, Rifat	Expansion idea discussion	All Group Members	Valuable
18/08/2025 (Lab)	Shadman, Barida	Tested system under extreme conditions	All Group Members	Reliable
19/08/2025 (EEE Dept)	Shadman, Rifat	Presentation draft review	All Group Members	Approved
20/08/2025 (Online)	Shadman, Barida	Created user manual for system	All Group Members	Informative
21/08/2025 (Lab)	Shadman	Hardware housing fit test	All Group Members	Perfect fit
22/08/2025 (Lab)	Shadman, Rifat	Battery calibration check	All Group Members	Stable runtime
23/08/2025 (Online)	Shadman, Barida	Final ATC query practice	All Group Members	Confidence

24/08/2025 (EEE Dept)	Shadman, Rifat	Prototype presentation	All Group Members	Positive
25/08/2025 (Lab)	Shadman	Post-feedback fixes	All Group Members	Implemented
26/08/2025 (Online)	Shadman, Rifat	Final logbook check	All Group Members	Accurate
27/08/2025 (Lab)	Shadman, Barida	Submission packaging arranged	All Group Members	Ready
28/08/2025 (Online)	Shadman, Rifat	Backup files upload to the cloud	All Group Members	Completed
29/08/2025 (Home)	Shadman	Device cleaning and polish	All Group Members	Clean finish
30/08/2025 (EEE Dept)	Shadman, Rifat, Barida	FYDP-C wrap-up meeting	All Group Members	Approved
31/08/2025 (Online)	Shadman, Rifat	Flex sensor damaged – ordered new	All Group Members	Track shipment
01/09/2025 (Lab)	Shadman	Replaced Flex sensor and retested	All Group Members	Working
02/09/2025 (Lab)	Shadman, Barida	ESP32 overheating issue observed	All Group Members	Add a heat sink
03/09/2025 (EEE Dept)	Shadman, Rifat	Bought a new ESP32 module	All Group Members	Expense recorded
04/09/2025 (Lab)	Shadman	Retested gestures with new ESP	All Group Members	Smooth
05/09/2025 (Lab)	Shadman, Barida	Housing adjusted for the new module	All Group Members	Better airflow
06/09/2025 (Lab)	Shadman, Rifat	Rebuilt wiring and retested	All Group Members	Verified

07/09/2025 (Online)	Shadman, Barida	Began app interface design	All Group Members	A promising idea
08/09/2025 (Home)	Shadman	Firebase testing for app data logging	All Group Members	Stable
09/09/2025 (Lab)	Shadman, Rifat	Linked ESP32 with an app via Wi-Fi	All Group Members	Successful
10/09/2025 (Online)	Shadman, Barida	UI mock-up for monitoring app	All Group Members	Clean layout
11/09/2025 (Lab)	Shadman	Tested data sync between app and glove	All Group Members	Real-time update
12/09/2025 (EEE Dept)	Shadman, Rifat, Barida	Advisor feedback on app demo	All Group Members	Continue refining
13/09/2025 (Online)	Shadman, Barida	App bug fixing and color scheme update	All Group Members	Approved
14/09/2025 (Lab)	Shadman	Mounted modules in housing	All Group Members	Firm structure
15/09/2025 (Lab)	Shadman, Rifat	Load test under continuous use	All Group Members	Stable for 5 hrs
16/09/2025 (Online)	Shadman, Barida	Report progress meeting	All Group Members	On schedule
17/09/2025 (Lab)	Shadman	Tested gesture accuracy in various angles	All Group Members	>90% success
18/09/2025 (Online)	Shadman, Rifat	Drafted poster and brochure	All Group Members	Looks good
19/09/2025 (Lab)	Shadman, Barida	App notification feature added	All Group Members	Functional
20/09/2025 (EEE Dept)	Shadman, Rifat, Barida	Mid-September review with ATC	All Group Members	Excellent progress

21/09/2025 (Online)	Shadman, Barida	Finalized thesis chapter distribution	All Group Members	Divide tasks evenly
22/09/2025 (Lab)	Shadman, Rifat	Captured demo videos for report	All Group Members	Good visuals
23/09/2025 (Home)	Shadman	Proof-reading user manual	All Group Members	Correct errors
24/09/2025 (Online)	Shadman, Barida	Checked app compatibility (Android 11+)	All Group Members	Works fine
25/09/2025 (Lab)	Shadman, Rifat	Tested remote load control via app	All Group Members	Smooth response
26/09/2025 (EEE Dept)	Shadman, Rifat, Barida	Discussed final demo schedule	All Group Members	Confirmed date
27/09/2025 (Online)	Shadman, Barida	Completed final report draft	All Group Members	Submit soon
28/09/2025 (Lab)	Shadman	Checked all wiring connections	All Group Members	Secure
29/09/2025 (Online)	Shadman, Rifat	ATC review session for report	All Group Members	Positive
30/09/2025 (Lab)	Shadman, Barida	Tested long-range Wi-Fi control	All Group Members	Up to 15m
01/10/2025 (EEE Dept)	Shadman, Rifat, Barida	Updated presentation slides	All Group Members	Looks great
02/10/2025 (Online)	Shadman, Barida	Created backup copy of app code	All Group Members	Stored safely
03/10/2025 (Lab)	Shadman, Rifat	Tested app notification delay	All Group Members	Minimal lag
04/10/2025 (EEE Dept)	Shadman, Barida	Reviewed documentation	All Group Members	Approved

05/10/2025 (Online)	Shadman, Rifat	Discussed final video narration	All Group Members	Ready script
06/10/2025 (Lab)	Shadman	Tested housing ventilation	All Group Members	No overheating
07/10/2025 (Online)	Shadman, Barida	Final presentation dry run	All Group Members	Smooth
08/10/2025 (Lab)	Shadman	Checked all sensors before showcase	All Group Members	Stable
09/10/2025 (EEE Dept)	Shadman, Rifat, Barida	Final ATC feedback session	All Group Members	Impressive
10/10/2025 (Online)	Shadman, Barida	Report printing and binding plan	All Group Members	Scheduled
11/10/2025 (Lab)	Shadman	Tested full system inside housing	All Group Members	Reliable
12/10/2025 (Online)	Shadman, Rifat	Practiced for final demo Q&A	All Group Members	Confident
13/10/2025 (EEE Dept)	Shadman, Barida	Collected all documentation files	All Group Members	Verified
14/10/2025 (Lab)	Shadman	Rehearsed with faculty observers	All Group Members	Well presented
15/10/2025 (EEE Dept)	Shadman, Rifat, Barida	Final review and backup creation	All Group Members	Approved
16/10/2025 (EEE Dept)	Shadman, Rifat, Barida, Imtiaz	Final Product Showcase and Live Demo to ATC & Faculty	All Group Members	Excellent performance
17/10/2025 (Online)	Shadman, Rifat	Reviewed showcase feedback and notes	All Group Members	Record improvements
18/10/2025 (Lab)	Shadman, Barida	Took high-quality product photos	All Group Members	Good visuals

19/10/2025 (Online)	Shadman, Rifat	Finalized thesis formatting & references	All Group Members	Well written
20/10/2025 (EEE Dept)	Shadman, Barida	Printed and bound final report copies	All Group Members	Professional
21/10/2025 (Online)	Shadman, Rifat	Prepared submission documents & poster	All Group Members	Ready
22/10/2025 (EEE Dept)	Shadman, Rifat, Barida, Imtiaz	Submitted final thesis report and closed project	All Group Members	Project Completed

Related Code/Theory

APP

(Index.tsx):

```
import React, { useEffect, useState, useRef } from "react";
import {
  View,
  Text,
  StyleSheet,
  Animated,
  ScrollView,
  ImageBackground,
} from "react-native";
import database from "@react-native-firebase/database";

const Card = ({ label, value }: any) => {
  const fadeAnim = useRef(new Animated.Value(1)).current;
  const prevValue = useRef(value);

  useEffect(() => {
    if (prevValue.current !== value) {
      triggerBlink();
      prevValue.current = value;
    }
  }, [value]);

  const triggerBlink = () => {
    fadeAnim.setValue(0.5);
    Animated.sequence([
      Animated.timing(fadeAnim, {
```

```
        toValue: 1,
        duration: 300,
        useNativeDriver: true,
      }),
      Animated.timing(fadeAnim, {
        toValue: 0.5,
        duration: 300,
        useNativeDriver: true,
      }),
      Animated.timing(fadeAnim, {
        toValue: 1,
        duration: 300,
        useNativeDriver: true,
      }),
    ]).start();
  };

  return (
    <Animated.View style={[styles.card, { opacity: fadeAnim }]}>
      <Text style={styles.label}>{label}</Text>
      <Text style={styles.value}>{value}</Text>
    </Animated.View>
  );
};

// standard values (example ranges, adjust as needed)
const standardValues = [
  { label: "DO", range: "5 - 14 mg/L" },
  { label: "TDS", range: "0 - 500 ppm" },
```

```
  { label: "Distance", range: "N/A" },
  { label: "Nitrogen", range: "0 - 10 mg/L" },
  { label: "pH", range: "6.5 - 8.5" },
  { label: "Temperature", range: "0 - 35 °C" },
];

const SensorScreen = () => {
  const [data, setData] = useState<any>({});//controller

  useEffect(() => {
    const ref = database().ref("controller/"); // Firebase path
    const listener = ref.on("value", (snapshot) => {
      if (snapshot.exists()) {
        console.log(snapshot.val());
        setData(snapshot.val());
      }
    });

    return () => ref.off("value", listener);
  }, []);


  return (
    <ImageBackground
      source={require("@/assets/images/bg.png")}
      resizeMode="cover"
      style={{ flex: 1, height: "100%", width: "100%" }}
    >
      <Text style={styles.header}>Automation with Flex</Text>
```

```
    <ScrollView contentContainerStyle={styles.container}>
     <Card label="Emergency" value={data?.devices?.emergency} />
     <Card label="Fan" value={data?.devices?.fan} />
     <Card label="Light" value={data?.devices?.light} />
      <Card label="Alcohol Detected" value={data?.sensors?.alcohol_detected?"Yes":"No"}
/>
     <Card label="Humidity" value={data?.sensors?.humidity} />
     <Card label="MQ3" value={data?.sensors?.mq3} />
     <Card label="Temperature" value={data?.sensors?.temperature} />



    </ScrollView>

   </ImageBackground>
  );
};

export default SensorScreen;

const styles = StyleSheet.create({
  container: {
    flexGrow: 1,
    justifyContent: "space-around",
    alignItems: "center",
    flexDirection: "row",
    flexWrap: "wrap",
    paddingVertical: 20,
  },
  header: {
```

```
  fontSize: 24,
  fontWeight: "bold",
  marginBottom: 20,
  marginTop: 60,
  textAlign: "center",
  color: "#fff",
},
card: {
  width: "45%",
  height: 150,
  padding: 20,
  borderRadius: 15,
  backgroundColor: "#ffffff5c",
  elevation: 5,
  shadowColor: "#000",
  shadowOffset: { width: 0, height: 2 },
  shadowOpacity: 0.25,
  shadowRadius: 3.84,
  marginBottom: 15,
  alignItems: "center",
},
label: {
  fontSize: 16,
  fontWeight: "600",
  marginBottom: 8,
},
value: {
  fontSize: 30,
  color: "#000000",
```

```
  fontWeight: "700",
},
tableContainer: {
  width: "90%",
  marginTop: 30,
  padding: 15,
  borderRadius: 15,
  backgroundColor: "#ffffffa0",
},
tableTitle: {
  fontSize: 20,
  fontWeight: "700",
  marginBottom: 10,
  textAlign: "center",
},
tableRow: {
  flexDirection: "row",
  justifyContent: "space-between",
  paddingVertical: 6,
  borderBottomWidth: 1,
  borderBottomColor: "#ccc",
},
tableLabel: {
  fontSize: 16,
  fontWeight: "600",
},
tableValue: {
  fontSize: 16,
  fontWeight: "400",
```

```
    color: "#333",
  },
});
```

Layout.tsx:

```
import { Tabs } from 'expo-router';
import React from 'react';

import { HapticTab } from '@/components/haptic-tab';
import { IconSymbol } from '@/components/ui/icon-symbol';
import { Colors } from '@/constants/theme';
import { useColorScheme } from '@/hooks/use-color-scheme';

export default function TabLayout() {
  const colorScheme = useColorScheme();

  return (
    <Tabs
      screenOptions={{
        tabBarActiveTintColor: Colors[colorScheme ?? 'light'].tint,
        headerShown: false,
        tabBarButton: HapticTab,
      }}>
      <Tabs.Screen
        name="index"
        options={{
          title: 'Home',
            tabBarIcon: ({ color }) => <IconSymbol size={28} name="house.fill" color={color}
/>,
        }}
```

```
      />
      <Tabs.Screen
        name="explore"
        options={{
          title: 'Explore',
          tabBarIcon: ({ color }) => <IconSymbol size={28} name="paperplane.fill" color={color} />,
        }}
      />
    </Tabs>
  );
}
```

explore.tsx:

```
import { Image } from 'expo-image';
import { Platform, StyleSheet } from 'react-native';

import { Collapsible } from '@/components/ui/collapsible';
import { ExternalLink } from '@/components/external-link';
import ParallaxScrollView from '@/components/parallax-scroll-view';
import { ThemedText } from '@/components/themed-text';
import { ThemedView } from '@/components/themed-view';
import { IconSymbol } from '@/components/ui/icon-symbol';
import { Fonts } from '@/constants/theme';

export default function TabTwoScreen() {
  return (
    <ParallaxScrollView
      headerBackgroundColor={{ light: '#D0D0D0', dark: '#353636' }}
```

```
headerImage={
  <IconSymbol
    size={310}
    color="#808080"
    name="chevron.left.forwardslash.chevron.right"
    style={styles.headerImage}
  />
}>
<ThemedView style={styles.titleContainer}>
  <ThemedText
    type="title"
    style={{
      fontFamily: Fonts.rounded,
    }}>
    Explore
  </ThemedText>
</ThemedView>
<ThemedText>This app includes example code to help you get started.</ThemedText>
<Collapsible title="File-based routing">
  <ThemedText>
    This app has two screens:{' '}
    <ThemedText type="defaultSemiBold">app/(tabs)/index.tsx</ThemedText> and{' '}
    <ThemedText type="defaultSemiBold">app/(tabs)/explore.tsx</ThemedText>
  </ThemedText>
  <ThemedText>
    The layout file in <ThemedText type="defaultSemiBold">app/(tabs)/_layout.tsx</ThemedText>{' '}
    sets up the tab navigator.
  </ThemedText>
```

```
      <ExternalLink href="https://docs.expo.dev/router/introduction">
        <ThemedText type="link">Learn more</ThemedText>
      </ExternalLink>
    </Collapsible>
    <Collapsible title="Android, iOS, and web support">
      <ThemedText>
          You can open this project on Android, iOS, and the web. To open the web version, press{' '}
        <ThemedText type="defaultSemiBold">w</ThemedText> in the terminal running this project.
      </ThemedText>
    </Collapsible>
    <Collapsible title="Images">
      <ThemedText>
          For static images, you can use the <ThemedText type="defaultSemiBold">@2x</ThemedText> and{' '}
        <ThemedText type="defaultSemiBold">@3x</ThemedText> suffixes to provide files for
        different screen densities
      </ThemedText>
      <Image
        source={require('@/assets/images/react-logo.png')}
        style={{ width: 100, height: 100, alignSelf: 'center' }}
      />
      <ExternalLink href="https://reactnative.dev/docs/images">
        <ThemedText type="link">Learn more</ThemedText>
      </ExternalLink>
    </Collapsible>
    <Collapsible title="Light and dark mode components">
      <ThemedText>
        This template has light and dark mode support. The{' '}
```

```
            <ThemedText type="defaultSemiBold">useColorScheme()</ThemedText> hook lets
you inspect
              what the user&apos;s current color scheme is, and so you can adjust UI colors
accordingly.
          </ThemedText>
          <ExternalLink href="https://docs.expo.dev/develop/user-interface/color-themes/">
            <ThemedText type="link">Learn more</ThemedText>
          </ExternalLink>
        </Collapsible>
        <Collapsible title="Animations">
          <ThemedText>
            This template includes an example of an animated component. The{' '}
              <ThemedText type="defaultSemiBold">components/HelloWave.tsx</ThemedText>
component uses
            the powerful{' '}
            <ThemedText type="defaultSemiBold" style={{ fontFamily: Fonts.mono }}>
              react-native-reanimated
            </ThemedText>{' '}
            library to create a waving hand animation.
          </ThemedText>
          {Platform.select({
            ios: (
              <ThemedText>
                                                                  The <ThemedText
type="defaultSemiBold">components/ParallaxScrollView.tsx</ThemedText>{' '}
                component provides a parallax effect for the header image.
              </ThemedText>
            ),
          })}
        </Collapsible>
      </ParallaxScrollView>
```

```
  );
}

const styles = StyleSheet.create({
  headerImage: {
    color: '#808080',
    bottom: -90,
    left: -35,
    position: 'absolute',
  },
  titleContainer: {
    flexDirection: 'row',
    gap: 8,
  },
});
```

modal.tsx:

```
import { Link } from 'expo-router';
import { StyleSheet } from 'react-native';

import { ThemedText } from '@/components/themed-text';
import { ThemedView } from '@/components/themed-view';

export default function ModalScreen() {
  return (
    <ThemedView style={styles.container}>
      <ThemedText type="title">This is a modal</ThemedText>
      <Link href="/" dismissTo style={styles.link}>
        <ThemedText type="link">Go to home screen</ThemedText>
```

```
    </Link>
   </ThemedView>
  );
}

const styles = StyleSheet.create({
  container: {
    flex: 1,
    alignItems: 'center',
    justifyContent: 'center',
    padding: 20,
  },
  link: {
    marginTop: 15,
    paddingVertical: 15,
  },
});
```

theme.ts:

```
import { Platform } from 'react-native';

const tintColorLight = '#0a7ea4';
const tintColorDark = '#fff';

export const Colors = {
  light: {
    text: '#11181C',
    background: '#fff',
    tint: tintColorLight,
```

```
    icon: '#687076',
    tabIconDefault: '#687076',
    tabIconSelected: tintColorLight,
  },
  dark: {
    text: '#ECEDEE',
    background: '#151718',
    tint: tintColorDark,
    icon: '#9BA1A6',
    tabIconDefault: '#9BA1A6',
    tabIconSelected: tintColorDark,
  },
};

export const Fonts = Platform.select({
  ios: {
    /** iOS `UIFontDescriptorSystemDesignDefault` */
    sans: 'system-ui',
    /** iOS `UIFontDescriptorSystemDesignSerif` */
    serif: 'ui-serif',
    /** iOS `UIFontDescriptorSystemDesignRounded` */
    rounded: 'ui-rounded',
    /** iOS `UIFontDescriptorSystemDesignMonospaced` */
    mono: 'ui-monospace',
  },
  default: {
    sans: 'normal',
    serif: 'serif',
    rounded: 'normal',
```

```
    mono: 'monospace',
  },
  web: {
    sans: "system-ui, -apple-system, BlinkMacSystemFont, 'Segoe UI', Roboto, Helvetica, Arial, sans-serif",
    serif: "Georgia, 'Times New Roman', serif",
    rounded: "'SF Pro Rounded', 'Hiragino Maru Gothic ProN', Meiryo, 'MS PGothic', sans-serif",
    mono: "SFMono-Regular, Menlo, Monaco, Consolas, 'Liberation Mono', 'Courier New', monospace",
  },
});
```

Room Simulation:

```
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>
#include <DHT.h>

// Pin configuration
#define BUZZER_PIN 2
#define DHT_PIN A2
#define MQ3_PIN A1
#define RELAY_CH1 8  // Fan
#define RELAY_CH2 7  // Light

#define DHT_TYPE DHT22

// OLED config
#define SCREEN_WIDTH 128
#define SCREEN_HEIGHT 64
#define OLED_ADDR 0x3C

Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, -1);

// DHT Sensor
DHT dht(DHT_PIN, DHT_TYPE);

// MQ3 Threshold
const int MQ3_THRESHOLD = 3000;

// Device states
```

```
bool fanState = false;
bool lightState = false;
bool buzzerState = false;
bool alcoholDetected = false;

// Sensor values
float temperature = 0;
float humidity = 0;
int mq3Value = 0;

// Timing variables
unsigned long lastSensorRead = 0;
unsigned long lastDisplayUpdate = 0;
const unsigned long SENSOR_READ_INTERVAL = 2000;
const unsigned long DISPLAY_UPDATE_INTERVAL = 1000;

void setup() {
  Serial.begin(9600);

  // Initialize pins
  pinMode(BUZZER_PIN, OUTPUT);
  pinMode(RELAY_CH1, OUTPUT);
  pinMode(RELAY_CH2, OUTPUT);
  pinMode(MQ3_PIN, INPUT);

  digitalWrite(RELAY_CH1, LOW); // Relay OFF
  digitalWrite(RELAY_CH2, LOW); // Relay OFF
  digitalWrite(BUZZER_PIN, LOW); // Buzzer OFF
```

```
  // Initialize DHT
  dht.begin();

  // Initialize OLED
  if (!display.begin(SSD1306_SWITCHCAPVCC, OLED_ADDR)) {
    Serial.println("OLED allocation failed");
    while (1);
  }
  display.clearDisplay();
  display.setTextSize(1);
  display.setTextColor(WHITE);
  display.setCursor(0, 0);
  display.println("Dual Relay System");
  display.println("Starting...");
  display.display();
  delay(1000);
}

void loop() {
  unsigned long currentTime = millis();
  digitalWrite(BUZZER_PIN, HIGH);
  // Update OLED every 1s
  if (currentTime - lastDisplayUpdate > DISPLAY_UPDATE_INTERVAL) {
    updateOLEDDisplay();
    lastDisplayUpdate = currentTime;
  }
  delay(100); // Small delay to avoid blocking
}
```

```
// Functions

void readDHTSensor() {
  float newTemp = dht.readTemperature();
  float newHumidity = dht.readHumidity();

  if (!isnan(newTemp)) temperature = newTemp;
  if (!isnan(newHumidity)) humidity = newHumidity;
}

void readMQ3Sensor() {
  mq3Value = analogRead(MQ3_PIN);
  alcoholDetected = (mq3Value > MQ3_THRESHOLD);

  if (alcoholDetected && !buzzerState) {
    buzzerState = true;
    digitalWrite(BUZZER_PIN, HIGH);
  } else if (!alcoholDetected && buzzerState) {
    buzzerState = false;
    digitalWrite(BUZZER_PIN, LOW);
  }
}

void processDevices() {
  // Fan Control Example: ON if Temp > 30°C
  if (temperature > 30 && !fanState) {
    fanState = true;
    digitalWrite(RELAY_CH1, LOW); // Relay ON
    Serial.println(" FAN TURNED ON");
```

```
  } else if (temperature <= 30 && fanState) {
    fanState = false;
    digitalWrite(RELAY_CH1, HIGH); // Relay OFF
    Serial.println(" FAN TURNED OFF");
  }

  // Light Control Example: ON if Alcohol detected
  if (alcoholDetected && !lightState) {
    lightState = true;
    digitalWrite(RELAY_CH2, LOW); // Relay ON
    Serial.println(" LIGHT TURNED ON");
  } else if (!alcoholDetected && lightState) {
    lightState = false;
    digitalWrite(RELAY_CH2, HIGH); // Relay OFF
    Serial.println("LIGHT TURNED OFF");
  }
}
void updateOLEDDisplay() {
  display.clearDisplay();
  display.setCursor(0, 0);

  display.print("Temp: "); display.print(27.3); display.println("C");
  display.print("Hum: "); display.print(84); display.println("%");

  display.print("Fan: "); display.println("OFF");
  display.print("Light: "); display.println("OFF");

  display.print("MQ3: "); display.print(1023);
  display.println(" Emergency!");
```

```
  display.print("Buzzer: "); display.println("ON");

  display.display();
}
```

Home Simulation with Flex and ESP32:

```
#include <WiFi.h>
#include <Firebase_ESP_Client.h>
#include <DHT.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>

// Firebase configuration
const char* FIREBASE_HOST = "flex-562fb-default-rtdb.firebaseio.com";
const char* FIREBASE_AUTH = "QhKe1H0KYcBc2cLXaqNcqGwFoFjbMMgQjuA8ASYL";
const char* WIFI_SSID = "Home Automation";
const char* WIFI_PASS = "11111111";

// OLED Configuration
#define SCREEN_WIDTH 128
#define SCREEN_HEIGHT 64
#define OLED_ADDR 0x3C
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, -1);

// Dual Channel Relay Pins
#define RELAY_CH1 33      // Channel 1 (Fan)
#define RELAY_CH2 19      // Channel 2 (Light)
```

```
#define BUZZER_PIN 4
#define DHT_PIN 32        // DHT22 data pin
#define MQ3_PIN 34        // MQ3 analog pin
#define DHT_TYPE DHT22

// I2C Pins for OLED
#define SDA_PIN 21
#define SCL_PIN 22

// Initialize DHT sensor
DHT dht(DHT_PIN, DHT_TYPE);

// Individual thresholds for each finger
const int THUMB_LOWER = 900;
const int THUMB_UPPER = 1400;
const int INDEX_LOWER = 800;
const int INDEX_UPPER = 1500;
const int MIDDLE_LOWER = 1300;
const int MIDDLE_UPPER = 1700;
const int RING_LOWER = 950;
const int RING_UPPER = 1800;
const int PINKY_LOWER = 1400;
const int PINKY_UPPER = 1750;

// MQ3 Threshold
const int MQ3_THRESHOLD = 3000;

// Device states
bool fanState = false;
```

```
bool lightState = false;
bool buzzerState = false;

// Sensor values
float temperature = 0;
float humidity = 0;
int mq3Value = 0;
bool alcoholDetected = false;

// Gesture detection states
bool thumbTriggered = false;
bool indexTriggered = false;
bool middleTriggered = false;
bool ringTriggered = false;
bool pinkyTriggered = false;

// Firebase objects
FirebaseData fbdo;
FirebaseAuth auth;
FirebaseConfig config;

// Sensor values from Firebase
int thumbValue = 0;
int indexValue = 0;
int middleValue = 0;
int ringValue = 0;
int pinkyValue = 0;

// Timing variables
```

```
unsigned long lastSensorRead = 0;
unsigned long lastDisplayUpdate = 0;
const unsigned long SENSOR_READ_INTERVAL = 2000;
const unsigned long DISPLAY_UPDATE_INTERVAL = 1000;

void setup() {
  Serial.begin(115200);

  // Initialize I2C for OLED
  Wire.begin(SDA_PIN, SCL_PIN);

  // Initialize OLED
  if(!display.begin(SSD1306_SWITCHCAPVCC, OLED_ADDR)) {
    Serial.println("OLED allocation failed");
    while(1);
  }
  display.clearDisplay();
  display.display();
  display.setTextSize(1);
  display.setTextColor(WHITE);

  // Show startup message on OLED
  display.clearDisplay();
  display.setCursor(0,0);
  display.println("Dual Relay System");
  display.println("Starting...");
  display.display();

  // Initialize pins
```

```
pinMode(RELAY_CH1, OUTPUT);
pinMode(RELAY_CH2, OUTPUT);
pinMode(BUZZER_PIN, OUTPUT);
pinMode(MQ3_PIN, INPUT);

// Start with devices OFF (Relay modules are usually ACTIVE LOW)
// If your relay is ACTIVE HIGH, change LOW to HIGH and HIGH to LOW
digitalWrite(RELAY_CH1, HIGH); // Relay OFF
digitalWrite(RELAY_CH2, HIGH); // Relay OFF
digitalWrite(BUZZER_PIN, LOW); // Buzzer OFF

// Initialize DHT22
dht.begin();

// Update OLED
display.clearDisplay();
display.setCursor(0,0);
display.println("Connecting WiFi...");
display.display();

// Connect to WiFi
WiFi.begin(WIFI_SSID, WIFI_PASS);
Serial.print("Connecting to WiFi");
while (WiFi.status() != WL_CONNECTED) {
  delay(500);
  Serial.print(".");
  display.print(".");
  display.display();
}
```

```
display.clearDisplay();
display.setCursor(0,0);
display.println("WiFi Connected!");
display.print("IP: ");
display.println(WiFi.localIP().toString());
display.display();
delay(1000);

// Initialize Firebase
config.host = FIREBASE_HOST;
config.signer.tokens.legacy_token = FIREBASE_AUTH;
Firebase.begin(&config, &auth);
Firebase.reconnectWiFi(true);

display.clearDisplay();
display.setCursor(0,0);
display.println("Connecting to");
display.println("Firebase...");
display.display();

Serial.println("\nConnecting to Firebase...");
while (!Firebase.ready()) {
  delay(100);
  Serial.print(".");
  display.print(".");
  display.display();
}
```

```
  display.clearDisplay();
  display.setCursor(0,0);
  display.println("Dual Relay System");
  display.println("Ready!");
  display.display();
  delay(1000);

  Serial.println("Dual Relay Control System Ready!");
}

void loop() {
  unsigned long currentTime = millis();

  // Read DHT22 and MQ3 sensors every 2 seconds
  if (currentTime - lastSensorRead > SENSOR_READ_INTERVAL) {
    readDHTSensor();
    readMQ3Sensor();
    lastSensorRead = currentTime;
  }

  // Update OLED display every second
  if (currentTime - lastDisplayUpdate > DISPLAY_UPDATE_INTERVAL) {
    updateOLEDDisplay();
    lastDisplayUpdate = currentTime;
  }

  // Read flex sensors and process gestures every second
  if (Firebase.ready()) {
    readFlexSensorValues();
```

```
    checkThresholds();
    processGestures();
    sendAllDataToFirebase();
    updateSerialDisplay();
  }

  delay(1000);
}

void updateOLEDDisplay() {
  display.clearDisplay();
  display.setCursor(0,0);

  // Line 1: Temperature and Humidity
  display.print("T:");
  display.print(temperature, 1);
  display.print("C H:");
  display.print(humidity, 0);
  display.println("%");

  // Line 2: Fan state and Light state
  display.print("Fan:");
  display.print(fanState ? "ON " : "OFF");
  display.setCursor(70, 8);
  display.print("Light:");
  display.println(lightState ? "ON" : "OFF");

  // Line 3: Alcohol detection status
  display.print("Alcohol:");
```

```
  if (alcoholDetected) {
    display.println("DETECTED!");
  } else {
    display.println("Normal");
  }

  // Line 4: MQ3 value
  display.print("MQ3:");
  display.println(mq3Value);

  // Line 5: Emergency state
  display.print("Emergency:");
  display.println(buzzerState ? "ACTIVE" : "INACTIVE");

  // Line 6: WiFi and Firebase status
  display.print("WiFi:");
  display.print(WiFi.status() == WL_CONNECTED ? "OK" : "X");
  display.setCursor(70, 40);
  display.print("FB:");
  display.println(Firebase.ready() ? "OK" : "X");

  display.display();
}

void readDHTSensor() {
  float newTemp = dht.readTemperature();
  float newHumidity = dht.readHumidity();

  if (!isnan(newTemp)) temperature = newTemp;
```

```
  if (!isnan(newHumidity)) humidity = newHumidity;
}

void readMQ3Sensor() {
  mq3Value = analogRead(MQ3_PIN);
  alcoholDetected = (mq3Value > MQ3_THRESHOLD);

  if (alcoholDetected && !buzzerState) {
    buzzerState = true;
    digitalWrite(BUZZER_PIN, HIGH);
  }
}

void readFlexSensorValues() {
  if (Firebase.RTDB.getInt(&fbdo, "/flexSensors/thumb")) thumbValue = fbdo.intData();
  if (Firebase.RTDB.getInt(&fbdo, "/flexSensors/index")) indexValue = fbdo.intData();
  if (Firebase.RTDB.getInt(&fbdo, "/flexSensors/middle")) middleValue = fbdo.intData();
  if (Firebase.RTDB.getInt(&fbdo, "/flexSensors/ring")) ringValue = fbdo.intData();
  if (Firebase.RTDB.getInt(&fbdo, "/flexSensors/pinky")) pinkyValue = fbdo.intData();
}

void checkThresholds() {
  // Thumb (Fan ON)
  if ((thumbValue < THUMB_LOWER || thumbValue > THUMB_UPPER) && !thumbTriggered) {
    thumbTriggered = true;
  } else if (thumbValue >= THUMB_LOWER && thumbValue <= THUMB_UPPER) {
    thumbTriggered = false;
  }
```

```
 // Index (Fan OFF)
 if ((indexValue < INDEX_LOWER || indexValue > INDEX_UPPER) && !indexTriggered)
{
   indexTriggered = true;
 } else if (indexValue >= INDEX_LOWER && indexValue <= INDEX_UPPER) {
   indexTriggered = false;
 }

 // Middle (Light ON)
   if ((middleValue < MIDDLE_LOWER || middleValue > MIDDLE_UPPER) &&
!middleTriggered) {
   middleTriggered = true;
 } else if (middleValue >= MIDDLE_LOWER && middleValue <= MIDDLE_UPPER) {
   middleTriggered = false;
 }

 // Ring (Light OFF)
 if ((ringValue < RING_LOWER || ringValue > RING_UPPER) && !ringTriggered) {
   ringTriggered = true;
 } else if (ringValue >= RING_LOWER && ringValue <= RING_UPPER) {
   ringTriggered = false;
 }

 // Pinky (Buzzer)
 if ((pinkyValue < PINKY_LOWER || pinkyValue > PINKY_UPPER) && !pinkyTriggered)
{
   pinkyTriggered = true;
 } else if (pinkyValue >= PINKY_LOWER && pinkyValue <= PINKY_UPPER) {
   pinkyTriggered = false;
```

```
    if (!alcoholDetected && buzzerState) {
      buzzerState = false;
      digitalWrite(BUZZER_PIN, LOW);
    }
  }
}

void processGestures() {
  // Fan Control - Relay Channel 1
  if (thumbTriggered && !fanState) {
    fanState = true;
    digitalWrite(RELAY_CH1, LOW); // Relay ON
    Serial.println(" FAN TURNED ON");
  }

  if (indexTriggered && fanState) {
    fanState = false;
    digitalWrite(RELAY_CH1, HIGH); // Relay OFF
    Serial.println(" FAN TURNED OFF");
  }

  // Light Control - Relay Channel 2
  if (middleTriggered && !lightState) {
    lightState = true;
    digitalWrite(RELAY_CH2, LOW); // Relay ON
    Serial.println(" LIGHT TURNED ON");
  }

  if (ringTriggered && lightState) {
```

```
    lightState = false;
    digitalWrite(RELAY_CH2, HIGH); // Relay OFF
    Serial.println(" LIGHT TURNED OFF");
  }

  // Buzzer Control
  if (pinkyTriggered && !buzzerState && !alcoholDetected) {
    buzzerState = true;
    digitalWrite(BUZZER_PIN, HIGH);
  } else if (!pinkyTriggered && buzzerState && !alcoholDetected) {
    buzzerState = false;
    digitalWrite(BUZZER_PIN, LOW);
  }
}

void sendAllDataToFirebase() {
  bool success = true;

  // Send device states
  success &= Firebase.RTDB.setString(&fbdo, "/controller/devices/fan", fanState ? "ON" : "OFF");
  success &= Firebase.RTDB.setString(&fbdo, "/controller/devices/light", lightState ? "ON" : "OFF");
  success &= Firebase.RTDB.setString(&fbdo, "/controller/devices/emergency", buzzerState ? "ACTIVE" : "INACTIVE");

  // Send sensor data
  success &= Firebase.RTDB.setFloat(&fbdo, "/controller/sensors/temperature", temperature);
  success &= Firebase.RTDB.setFloat(&fbdo, "/controller/sensors/humidity", humidity);
  success &= Firebase.RTDB.setInt(&fbdo, "/controller/sensors/mq3", mq3Value);
```

```
    success &= Firebase.RTDB.setBool(&fbdo, "/controller/sensors/alcohol_detected", alcoholDetected);

  // Send relay status
  success &= Firebase.RTDB.setBool(&fbdo, "/controller/relay/ch1_status", fanState);
  success &= Firebase.RTDB.setBool(&fbdo, "/controller/relay/ch2_status", lightState);

  if (!success) {
    Serial.println("Firebase Error: " + fbdo.errorReason());
  }
}

void updateSerialDisplay() {
  Serial.println("=== DUAL RELAY SYSTEM STATUS ===");
  Serial.print("FAN: "); Serial.println(fanState ? "ON" : "OFF");
  Serial.print("LIGHT: "); Serial.println(lightState ? "ON" : "OFF");
  Serial.print("EMERGENCY: "); Serial.println(buzzerState ? "ACTIVE" : "INACTIVE");
  Serial.print("Temperature: "); Serial.print(temperature); Serial.println("°C");
  Serial.print("Humidity: "); Serial.print(humidity); Serial.println("%");
  Serial.print("MQ3: "); Serial.print(mq3Value);
  Serial.println(alcoholDetected ? " ALCOHOL DETECTED!" : " Normal");
  Serial.println("================================");
}
```

Hand Gloves:

```
#include <WiFi.h>
#include <Firebase_ESP_Client.h>

// Firebase configuration
```

```
const char* FIREBASE_HOST = "flex-562fb-default-rtdb.firebaseio.com";
const char* FIREBASE_AUTH = "QhKe1H0KYcBc2cLXaqNcqGwFoFjbMMgQjuA8ASYL";
const char* WIFI_SSID = "Home Automation";
const char* WIFI_PASS = "11111111";

// SAFE pins for ESP32 DevKit V1
const int FLEX_PINS[5] = {33, 32, 35, 34, 39};

String fingerNames[5] = {"thumb", "index", "middle", "ring", "pinky"};

// Firebase objects
FirebaseData fbdo;
FirebaseAuth auth;
FirebaseConfig config;

unsigned long lastDataSend = 0;
const unsigned long SEND_INTERVAL = 100; // Update every 100ms

void setup() {
  Serial.begin(115200);

  // Initialize flex sensor pins
  for(int i = 0; i < 5; i++) {
    pinMode(FLEX_PINS[i], INPUT);
  }

  Serial.println("Initializing 5 Flex Sensors with ESP32...");
  Serial.println("Using raw analog readings (no averaging)");
```

```
  Serial.println("Updates every 100ms");

  // Connect to WiFi
  WiFi.begin(WIFI_SSID, WIFI_PASS);
  Serial.print("Connecting to WiFi");
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("\nWiFi Connected! IP: " + WiFi.localIP().toString());

  // Initialize Firebase
  config.host = FIREBASE_HOST;
  config.signer.tokens.legacy_token = FIREBASE_AUTH;

  Firebase.begin(&config, &auth);
  Firebase.reconnectWiFi(true);

  Serial.println("Connecting to Firebase...");
  while (!Firebase.ready()) {
    delay(100);
    Serial.print(".");
  }

  Serial.println("Firebase Ready!");
  Serial.println("System Started - Raw Analog Readings Every 100ms");
  Serial.println("==================================================");
}
```

```
void loop() {
  // Send raw analog readings to Firebase every 100ms
  if (Firebase.ready() && (millis() - lastDataSend > SEND_INTERVAL)) {
    readAndSendData();
    lastDataSend = millis();
  }

  delay(1); // Small delay to prevent watchdog issues
}

void readAndSendData() {
  bool success = true;

  // Read and send raw analog readings for each sensor
  for(int i = 0; i < 5; i++) {
    int rawValue = analogRead(FLEX_PINS[i]);
    String path = "/flexSensors/" + fingerNames[i];
    success &= Firebase.RTDB.setInt(&fbdo, path.c_str(), rawValue);

    // Print each sensor value
    Serial.print(fingerNames[i]);
    Serial.print(": ");
    Serial.print(rawValue);
    Serial.print(" | ");
  }

  if (success) {
    Serial.println("Sent");
  } else {
```

```
    Serial.println("Error: " + fbdo.errorReason());
  }
}
```

Flex Simulation:

```
// Arduino Uno 5 Flex Sensor Reader
// Reads 5 flex sensors and prints values every 100ms

const int FLEX_PINS[5] = {A0, A1, A2, A3, A4}; // Use analog pins A0–A4
String fingerNames[5] = {"thumb", "index", "middle", "ring", "pinky"};

unsigned long lastDataSend = 0;
const unsigned long SEND_INTERVAL = 100; // 100 ms

void setup() {
  Serial.begin(9600);

  Serial.println("Initializing 5 Flex Sensors with Arduino Uno...");
  Serial.println("Using raw analog readings (no averaging)");
  Serial.println("Updates every 100ms");

  // Set pins as input
  for (int i = 0; i < 5; i++) {
    pinMode(FLEX_PINS[i], INPUT);
  }

  Serial.println("System Ready!");
  Serial.println("==================================================");
}
```

```
void loop() {
  if (millis() - lastDataSend > SEND_INTERVAL) {
    readAndPrintData();
    lastDataSend = millis();
  }
}

void readAndPrintData() {
  for (int i = 0; i < 5; i++) {
    int rawValue = analogRead(FLEX_PINS[i]);

    Serial.print(fingerNames[i]);
    Serial.print(": ");
    Serial.print(rawValue);
    Serial.print(" | ");
  }
  Serial.println();
}
```

Adafruit:

```
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>

#define SCREEN_WIDTH 128 // OLED width in pixels
#define SCREEN_HEIGHT 64 // OLED height in pixels
// Declaration for SSD1306 I2C
#define OLED_RESET    -1 // Reset pin # (or -1 if sharing Arduino reset)
```

```
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, OLED_RESET);
void setup() {
  // Initialize Serial (optional for debugging)
  Serial.begin(9600);

  // Initialize the OLED
  if(!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) { // 0x3C is the I2C address
    Serial.println(F("SSD1306 allocation failed"));
    for(;;);
  }
  display.clearDisplay(); // Clear the buffer
  display.setTextSize(2);      // Text size (1-8)
  display.setTextColor(SSD1306_WHITE); // Text color
  display.setCursor(0, 0);     // Start at top-left corner
  display.println("Hello");    // Print "Hello"
  display.display();           // Display buffer content
}
void loop() {
  // Nothing here
}
```