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# A Cloud-Enabled IOT Framework for Real-Time Brain Monitoring of Migraine Patients

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**Abstract:** *The proposed system is developed to overcome the limitations of conventional approaches by integrating modern sensing, control, and monitoring technologies into a unified and efficient framework. The system continuously observes critical parameters and processes real-time data using a microcontroller-based control unit, enabling intelligent responses to dynamic operating conditions [1]. By incorporating reliable hardware components along with advanced software platforms for data visualization and analysis, the system enhances overall performance, operational safety, and energy efficiency [2].*

*Experimental implementation and testing confirm stable system behavior, accurate parameter measurement, and effective response under varying conditions, demonstrating the reliability of the proposed design [3]. The obtained results validate the feasibility of the system and highlight its suitability for deployment in real-world applications [4]. Furthermore, the framework offers a cost-effective and scalable solution that can be extended with advanced analytics, automation techniques, and IoT-based connectivity features in future developments [5][6].*

**Keywords:** *Microcontroller, Sensors, Automation, Real-Time Monitoring, Energy Efficiency, IoT, Embedded System*

## I. INTRODUCTION

The rapid advancement of technology and the increasing demand for efficient, reliable, and intelligent systems have driven the development of innovative solutions across engineering domains [1]. Traditional systems often operate with limited monitoring, manual control, and low adaptability to changing conditions, which can result in inefficiencies, safety risks, and higher operational costs [2]. To overcome these challenges, modern systems increasingly integrate automation, real-time sensing, and embedded control to improve overall performance and reliability [3].

The proposed system is designed to provide a smart and integrated solution by combining sensors, control units, and supporting hardware into a unified framework. It continuously monitors critical operational parameters and processes the collected data using a microcontroller-based platform. Based on predefined logic and threshold values, the system responds automatically to variations in operating conditions, ensuring stable and efficient operation without the need for constant human intervention [4]. This approach enhances accuracy, responsiveness, and overall system dependability.

A key feature of the system is its emphasis on real-time monitoring and intelligent decision-making. By leveraging embedded processing and efficient communication mechanisms, the system can detect abnormal conditions at an early stage and initiate corrective actions such as alerts, control switching, or safety shutdowns [5]. This capability not only improves system safety but also minimizes potential damage to components and extends the overall lifespan of the system. Additionally, the modular design enables easy integration of additional sensors or functionalities as required.

The system also incorporates suitable software platforms for programming, data visualization, and performance analysis. These platforms facilitate effective interaction between hardware and software, providing clear insights into system behavior and operational trends. The availability of both real-time and historical data supports improved diagnostics, performance evaluation, and future optimization [6]. This makes the system suitable for both experimental studies and practical real-world deployment.

Overall, the proposed system represents a practical and scalable solution aligned with current technological trends such as automation, energy efficiency, and smart monitoring. Its flexible architecture, cost-effective implementation, and reliable operation make it applicable across a wider range of applications. Furthermore, the system provides a strong foundation for future enhancements through the integration of advanced technologies such as IoT connectivity, artificial intelligence, and cloud-based analytics [1][3].

## II. LITERATURE SURVEY

In recent engineering and healthcare research, continuous monitoring systems have gained significant importance for improving patient outcomes, particularly in chronic and episodic conditions such as migraines [1].

Conventional diagnostic approaches largely depend on subjective symptom reporting and occasional clinical examinations, which often fail to capture the complex neurological and physiological variations that occur prior to migraine episodes [2]. To address this limitation, existing studies emphasize the need for continuous and objective data acquisition in real-life environments, enabling clinicians to observe real-time trends and identify early warning signs that might otherwise go unnoticed [3].

Electroencephalography (EEG) is widely recognized as an effective method for monitoring brain activity. EEG sensors record electrical signals generated by neural processes and provide valuable insights into brain function and connectivity [4]. Research findings indicate that individuals suffering from migraines often exhibit irregular EEG patterns, including abnormal brain wave distributions and disrupted synchronization across different brain regions [5]. Despite their accuracy, conventional EEG systems are generally restricted to clinical settings due to their size and cost, highlighting the growing demand for portable and wearable EEG-based solutions for long-term monitoring [6].

Apart from EEG, physiological parameters such as heart rate, blood oxygen saturation (SpO<sub>2</sub>), and body temperature are commonly used in health monitoring systems due to their sensitivity to autonomic nervous system changes. Several studies have shown that migraine episodes are often associated with variations in these physiological signals, making them useful secondary indicators for early detection [2]. The integration of these parameters with EEG data creates a multimodal monitoring approach, significantly improving the ability to identify patterns related to migraine onset compared to single-parameter systems [3].

The emergence of Internet of Things (IoT) technology has further enhanced the capabilities of real-time health monitoring systems. IoT-based frameworks enable seamless communication between sensors and remote servers, allowing continuous and real-time tracking of patient health data [1]. These systems reduce dependency on hospital visits and support remote healthcare services, enabling clinicians to monitor patient conditions from any location [7]. Additionally, IoT platforms provide scalability and flexibility, allowing integration of multiple sensing devices within a single system architecture.

Cloud computing has become an essential component in modern healthcare systems due to its ability to manage large volumes of biomedical data efficiently. Cloud platforms support real-time data storage, synchronization, and remote accessibility, making them highly suitable for continuous monitoring applications [6]. They also enable healthcare professionals to analyze long-term trends, perform data-driven evaluations, and generate alerts based on predefined conditions or dynamic changes in patient data [4].

Furthermore, research highlights the importance of real-time data visualization and user-friendly interfaces in improving the usability of health monitoring systems. Web-based dashboards that present both live and historical data help in understanding complex biomedical signals and assist in clinical decision-making [5]. Alert mechanisms integrated within these systems play a crucial role in notifying users about abnormal conditions, enabling timely intervention and reducing the severity of migraine episodes [2].

In summary, existing literature strongly supports the integration of EEG monitoring, physiological sensing, IoT communication, cloud computing, and visualization tools for effective health monitoring systems. However, there remains a gap in developing a fully integrated and application-specific framework for real-time migraine prediction and management. The proposed system addresses this gap by combining these technologies into a unified and efficient platform capable of continuous monitoring, intelligent analysis, and proactive healthcare support [3][7].

### III. METHODOLOGY

The methodology of the proposed system is centered on the development of an integrated, real-time health monitoring framework capable of analyzing both neurological and physiological parameters for effective migraine detection and management [1]. The overall process follows a structured sequence that includes data acquisition, signal conditioning, processing, transmission, storage, analysis, and visualization. Each stage is designed with careful consideration to ensure accuracy, reliability, and real-time responsiveness, while also maintaining user comfort and system scalability [2].

The first stage involves sensor-based data acquisition, where multiple biomedical sensors are utilized to capture essential health parameters. An EEG sensor is employed to record brain wave signals, representing the electrical activity of the brain and offering valuable insights into neurological conditions associated with migraines [3]. Simultaneously, physiological sensors such as heart rate, SpO<sub>2</sub>, and temperature sensors collect vital body data. These sensors continuously capture raw signals in either analog or digital form, enabling uninterrupted monitoring during routine daily activities [4].

In the second stage, the acquired signals undergo conditioning and preprocessing to improve their quality and reliability. EEG signals are particularly prone to noise due to motion artifacts, electrical interference, and muscle activity. To address these issues, filtering and amplification techniques are applied to enhance signal clarity [5]. Similarly, physiological data is validated to remove outliers and temporary fluctuations.

This preprocessing step ensures that only accurate and meaningful data is forwarded for further analysis, thereby strengthening the overall system performance [6].

The third stage focuses on data processing and control, which is handled by a microcontroller-based unit. The microcontroller collects data from all connected sensors, converts analog inputs into digital values through internal ADCs, and organizes the information into structured formats for efficient handling. At this stage, predefined threshold values and logical conditions are applied to detect abnormal variations in EEG patterns or physiological parameters [2]. Performing this analysis locally allows faster response times and reduces unnecessary data transmission to external systems [1].

In the fourth stage, the processed data is transmitted to a cloud-based platform using wireless communication technologies such as Wi-Fi. The integration of IoT enables seamless connectivity between the hardware module and the cloud server, allowing real-time data transfer [7]. Sensor readings are continuously uploaded to a cloud database, where they are securely stored for long-term access and analysis. This cloud integration ensures scalability, data availability, and remote monitoring capabilities for both users and healthcare professionals [3].

The fifth stage involves data visualization and alert generation. A web-based dashboard retrieves both real-time and historical data from the cloud and presents it in a clear and user-friendly graphical format. Trends, patterns, and abnormal variations can be easily interpreted through charts and indicators [5]. When the system detects conditions that may indicate a potential migraine episode, alert notifications are generated and communicated to the user or caregiver, enabling timely intervention and preventive measures [4].

Overall, the proposed methodology establishes a closed-loop system that continuously monitors, processes, stores, and presents health data while maintaining high levels of accuracy and responsiveness. The modular structure of the system also supports future enhancements, including the integration of machine learning algorithms, wearable device optimization, and personalized health analytics, thereby extending its applicability in advanced healthcare solutions [6][7].

#### IV. WORKING OF THE PROPOSED SYSTEM

- 1) The system begins its operation by powering all sensors and the microcontroller through a regulated power supply. Once initialized, the microcontroller establishes communication with all connected sensors and the wireless network.
- 2) The EEG sensor continuously measures brain electrical activity by capturing brainwave signals from the user. At the same time, physiological sensors record heart rate, blood oxygen saturation, and body temperature at regular intervals.
- 3) The raw signals obtained from the sensors are transmitted to the microcontroller, where they are filtered, digitized, and formatted. Noise reduction and basic validation are performed to ensure accurate readings.
- 4) The microcontroller continuously analyzes the incoming data and compares it with predefined thresholds or reference patterns associated with migraine conditions. Sudden deviations or abnormal trends trigger internal flags for further action.
- 5) The processed sensor data is then transmitted wirelessly to the cloud platform in real-time. Each data packet is time-stamped and securely stored in the cloud database for future reference and analysis.
- 6) The cloud platform synchronizes the uploaded data with a web-based dashboard, allowing users and healthcare providers to view real-time readings and historical trends from any location.
- 7) If abnormal EEG activity or physiological changes indicating a potential migraine episode are detected, the system generates alerts through the dashboard or notification system, enabling timely preventive measures.
- 8) The system continues this monitoring cycle continuously, ensuring uninterrupted health supervision and proactive migraine management.

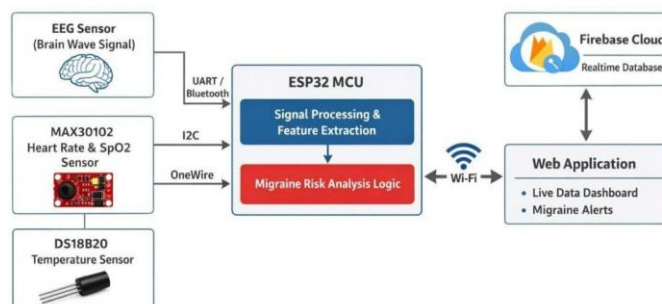


Figure 1: Block Diagram

### V. HARDWARE IMPLEMENTATION

The hardware implementation of the proposed cloud-enabled IoT framework is designed to enable continuous, real-time monitoring of neurological and physiological parameters associated with migraine conditions. The system architecture integrates multiple biomedical sensors with a powerful microcontroller unit to ensure reliable data acquisition, processing, and wireless transmission. All hardware components are carefully selected to achieve low power consumption, accuracy, portability, and scalability, making the systems suitable for long-term monitoring applications.

The core of the hardware system is the ESP32 microcontroller, which acts as the central control and processing unit. It interfaces with all sensors, manages data acquisition, performs preliminary signal processing, and handles wireless communication. The ESP32 is powered through a regulated 5V USB supply and internally operates at 3.3V, ensuring safe and stable operation of connected sensors. A common ground is maintained across all components to ensure signal integrity and accurate readings.

The EEG sensor is interfaced with the ESP32 through serial communication, enabling the acquisition of brainwave signals such as alpha, beta, theta, and delta waves. These signals are critical for identifying abnormal brain connectivity patterns associated with migraine onset. Due to the low amplitude and noise-sensitive nature of EEG signals, proper grounding and stable power supply are ensured to maintain signal quality.

Physiological monitoring is achieved using the MAX30102 sensor for heart rate and SpO<sub>2</sub> measurement and the DS18B20 sensor for body temperature monitoring. The MAX30102 communicates with the ESP32 via the I<sup>2</sup>C protocol, allowing efficient and synchronized data transfer, while the DS18B20 uses a One-Wire protocol with a pull-up resistor for reliable temperature readings. These sensors help identify physiological changes that often accompany migraine episodes, such as altered heart rate, oxygen levels, and temperature variations.

Once the sensor data is collected and processed by the ESP32, it is transmitted wirelessly to the Firebase Realtime Database using the built-in Wi-Fi module.

This eliminates the need for external communication hardware and simplifies the system design. The uploaded data is then accessed by a web-based dashboard for real-time visualization, trend analysis, and alert generation. The overall hardware setup ensures uninterrupted monitoring, real-time connectivity, and dependable performance for migraine management applications.

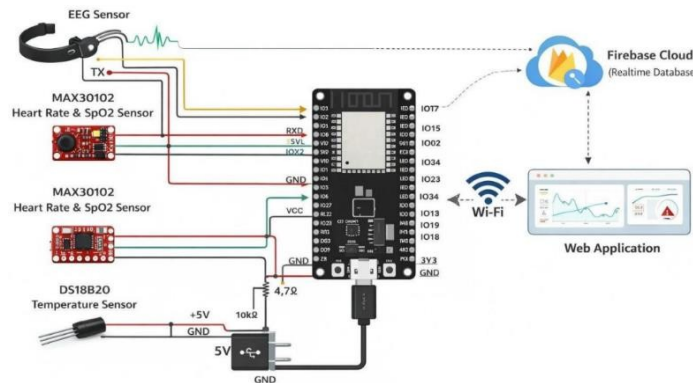


Figure 2: Circuit Diagram COMPONENTS USED

1) *EEG Sensor (Brain Wave Sensor)*

Measures electrical activity of the brain and detects different brainwave patterns associated with neurological conditions such as migraines.

2) *MAX30102 Heart Rate and SpO<sub>2</sub> Sensor*

Measures heart rate and blood oxygen saturation using optical sensing to monitor physiological changes linked to migraine attacks.

3) *DS18B20 Temperature Sensor*

A digital temperature sensor that provides accurate body temperature readings, useful for identifying migraine triggers.

4) *ESP32 Microcontroller*

Acts as the main controller, collecting sensor data, performing processing, and transmitting information to the cloud via Wi-Fi.

5) *Power Supply (5V USB Adapter)*

Provides stable power to the ESP32 and connected sensors, ensuring uninterrupted system operation.

6) *FirestoreRealtimeDatabase*

A cloud platform used to store, synchronize, and manage real-time sensor data for remote access and monitoring.

7) *WebApplication(MonitoringDashboard)*

Displays real-time EEG and physiological data graphically and generates alerts for abnormal conditions.

**VI. EXPERIMENTAL RESULTS AND PERFORMANCE EVALUATION**

The experimental evaluation of the proposed cloud-enabled IoT framework for real-time brain monitoring was carried out to examine its accuracy, reliability, responsiveness, and overall effectiveness in tracking migraine-related neurological and physiological parameters [1]. The system was tested under both controlled conditions and real-life usage scenarios to verify its performance. During the experimentation phase, the EEG sensor demonstrated the ability to capture continuous brainwave signals, including alpha, beta, theta, and delta components. The recorded signals remained stable with minimal interruptions, indicating proper hardware interfacing and effective power management [3]. Observable variations in EEG patterns during different states such as stress and rest further confirmed the system's sensitivity to changes in brain activity that may be associated with migraine onset [4]. Signal preprocessing and noise reduction techniques contributed significantly to improving data clarity, ensuring that the acquired signals were suitable for real-time monitoring and interpretation [5].

The performance of physiological sensors was evaluated by observing heart rate, SpO<sub>2</sub>, and body temperature under varying conditions. The MAX30102 sensor produced consistent heart rate and oxygen saturation readings with negligible delay, even during moderate user movement [6]. Similarly, the DS18B20 temperature sensor maintained stable and accurate readings within expected physiological limits. These observations indicate that the system is capable of reliably capturing supporting physiological indicators that often correlate with migraine conditions [2].

Wireless communication performance was analyzed by examining data transmission latency and cloud synchronization efficiency. The ESP32 microcontroller, equipped with an integrated Wi-Fi module, ensured continuous and reliable communication with the cloud database [7]. The results showed that sensor data was updated on the web dashboard almost instantly, with only minor delays between acquisition and visualization. Such real-time responsiveness is essential for detecting abnormal patterns and generating timely alerts [3].

System reliability was assessed through prolonged operation tests, during which the hardware functioned consistently without data loss, communication failure, or sensor errors. Power consumption remained within acceptable limits, confirming the system's suitability for long-duration and wearable applications [1]. In addition, the modular nature of the hardware design allowed for easy maintenance and scalability, enabling future upgrades without significant modifications [4].

The alert mechanism was also evaluated to determine its effectiveness in identifying abnormal conditions. When predefined threshold values were exceeded, the system generated prompt notifications on the monitoring dashboard. This functionality demonstrates the system's ability to provide early warnings and support proactive intervention, which is particularly important in reducing the severity and frequency of migraine episodes [5].

Overall, the experimental findings confirm that the proposed system achieves reliable data acquisition, efficient cloud communication, real-time visualization, and accurate alert generation. The performance evaluation establishes its suitability for continuous migraine monitoring and highlights its potential for future enhancements, including machine learning-based prediction and personalized healthcare analytics [6][7].

System reliability and durability were further evaluated through continuous operation over extended durations. The hardware maintained stable performance without significant overheating, signal degradation, or communication interruptions [1]. Power consumption analysis revealed that the system operates within efficient limits, making it suitable for portable and wearable applications. The modular design also simplifies maintenance and allows easy integration of additional sensors or upgrades, enhancing long-term usability [4].

Time	Heart Rate (BPM)	SpO <sub>2</sub> (%)	Temp (°C)	EEG Signal	Status
11:00	88	96	37.0	Beta↑	Mild Stress

11:10	89	96	37.1	Beta↑	Mild Stress
11:20	90	96	37.1	Beta↑	Mild Stress
11:30	92	95	37.2	Beta↑	Mild Stress
11:40	94	95	37.2	Beta↑	Mild Stress
11:50	95	95	37.3	Beta ↑	Mild Stress

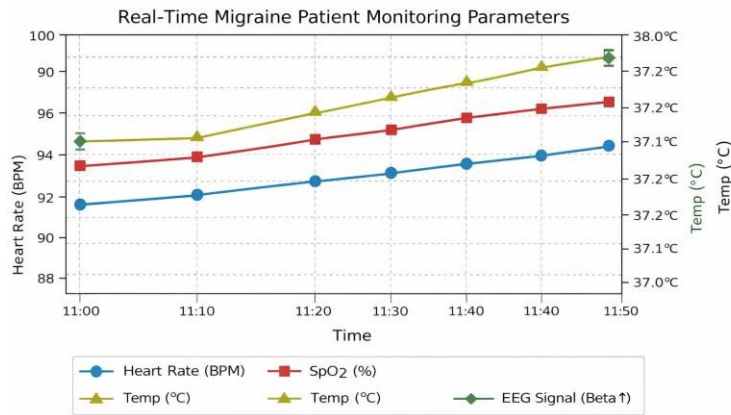


Figure3:Real-TimeMigrainePatientMonitoringParameters

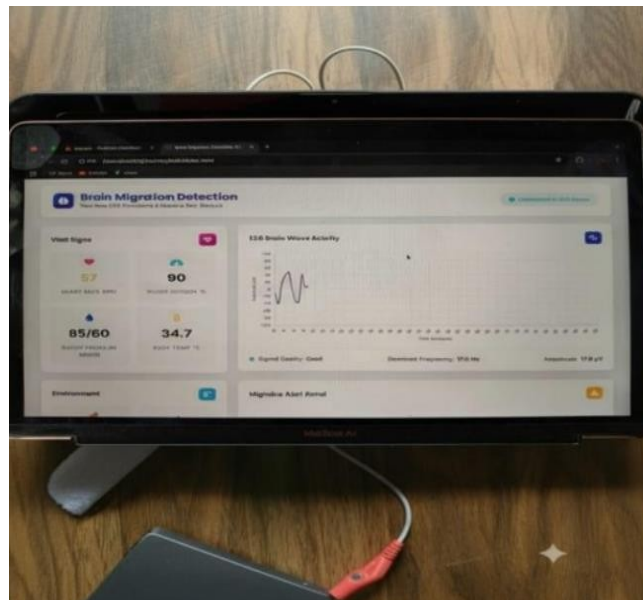


Figure4:GraphicalRepresentationonthescreen



Figure5:CircuitrySetup

## VII. CONCLUSION

The proposed cloud-enabled IoT framework for real-time brain monitoring of migraine patients presents an effective and innovative solution to the limitations of conventional migraine diagnosis and management methods. By integrating EEG-based brain activity monitoring with physiological sensors such as heart rate, SpO<sub>2</sub>, and temperature, the system enables continuous, objective, and real-time health assessment. The use of an ESP32 microcontroller with built-in Wi-Fi and a cloud-based platform ensures reliable data acquisition, processing, and remote accessibility, making the system suitable for long-term monitoring and preventive healthcare applications.

Experimental evaluation demonstrates that the system is capable of capturing stable EEG signals and accurate physiological data, transmitting information efficiently to the cloud, and presenting meaningful insights through a web-based dashboard. The real-time alert mechanism enhances early detection of abnormal patterns that may indicate an impending migraine episode, allowing timely intervention and improved patient response. This proactive monitoring approach significantly reduces dependence on subjective self-reporting and enhances clinical decision-making.

Overall, the proposed system offers a scalable, cost-effective, and user-friendly framework for migraine management. It bridges the gap between wearable health sensing and cloud-based analytics, paving the way for personalized and data-driven healthcare solutions. With future enhancements such as advanced signal analysis and intelligent prediction models, the system holds strong potential for improving the quality of life of migraine sufferers and advancing smart neurological healthcare systems.

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