International Journal of Academic Multidisciplinary Research (IJAMR)
ISSN: 2643-9670
Vol. 10 Issue 3 March - 2026, Pages: 193-198

IoT-Based Smart Pillow System for Early nDetection of Stroke Warning Signs through Heart Rate, Oxygen Level, and Motion Monitoring

Rogelio C. Samson, Arjay C. Marucot , Ren'z Butch S. Calma , Kimberly Dawn P. Jatulan

Rogelio C. Samson
San Miguel National High School and
Bulacan Agricultural State College
Bulacan, Philippines
rowell.c.samson@gmail.com

Arjay C. Marucot
Institute of Computer Studies
Bulacan Agricultural State College
Bulacan, Philippines
arjaymarucot@gmail.com

Ren'z Butch S. Calma
Master In Information Technology
Bulacan Agricultural State College
Bulacan, Philippines
crenzbutch@gmail.com

Kimberly Dawn P. Jatulan
Master In Information Technology
Bulacan Agricultural State College
Bulacan, Philippines
kimjatulan@gmail.com

Abstract— This study presents an IoT-based smart pillow monitoring system designed to provide continuous, non-intrusive monitoring of heart rate, oxygen saturation (SpO_2), and body motion as potential early indicators of stroke risk during sleep, promoting preventive healthcare and overall well-being through accessible home-based monitoring. Developed using an ESP32 microcontroller, simulated MAX30102 readings via a potentiometer, an MPU6050 motion sensor, a microphone for breathing sound detection, and a buzzer for alert notifications, the system utilizes innovative IoT and embedded technologies to support reliable and scalable health monitoring infrastructure. By emphasizing affordability and ease of deployment, the proposed system improves access to basic health monitoring for individuals with limited availability of clinical services. The system processes real-time multi-sensor data through basic filtering and threshold-based anomaly detection. Bench testing and preliminary user evaluation demonstrate that the prototype can reliably capture simulated physiological patterns, visualize them through a cloud-based dashboard, and deliver immediate alerts while maintaining user comfort. Although the system is constrained by sensor accuracy, Wi-Fi dependency, and the indirect nature of pillow-based measurements, the results confirm the feasibility of smart pillow-integrated sensing as a cost-effective solution for home-based health monitoring. This work provides a foundational framework for future enhancements, including improved sensing accuracy, long-term testing, and integration with medical-grade health platforms to further support early detection and preventive care.

Keywords— IoT (Internet of Things), Smart Pillow, ESP32 Microcontroller, SpO_2 Monitoring, MPU6050, Potentiometer, Embedded Sensors.

I. INTRODUCTION

Stroke remains a major global health threat and one of the leading causes of disability and mortality worldwide [1], [3]. Early physiological warning signs such as irregular breathing, heart rate fluctuations, reduced oxygen saturation, and sudden immobility often occur during sleep and typically go undetected due to the absence of continuous, non-intrusive monitoring. This challenge is intensified in developing regions, where limited access to hospital-grade systems and reliance on manual or wearable monitoring reduce the likelihood of early detection.

In Southeast Asia, particularly in the Philippines, stroke consistently ranks among the top causes of morbidity and mortality. Many households lack accessible nighttime monitoring solutions, and wearable devices often pose comfort issues for elderly or high-risk individuals. Prior studies on smart pillows and IoT-based health systems demonstrate the feasibility of embedding sensors into everyday objects [2], [4], yet multi-parameter, non-intrusive monitoring for stroke-related indicators remains limited.

To address this gap, this study proposes an IoTBased Smart Pillow Monitoring System. Specifically, the study aims (1) to develop a pillow-embedded system that monitors heart rate, SpO_2, breathing patterns, and motion; (2) to examine the system's ability to process and transmit multi-sensor data in real time; and (3) to assess the performance of its alert mechanism and identify limitations related to accuracy, comfort, and sensor behavior.

II. REVIEW OF RELATED LITERATURE

Smart pillows are pillows enhanced with technology sensors, connectivity, sometimes actuators to monitor, track, or improve sleep beyond merely providing head support. According to a recent overview, smart pillows may integrate sleep monitoring sensors, temperature regulation, adjustable support, or audio playback to offer a more personalized and data driven sleep environment. A seminal study introduced a smart pillow that uses temperature and humidity sensors embedded in strategic positions within the pillow. This design allowed for the continuous monitoring of physiological signs during sleep, such as body temperature and night sweating. Data collected are sent via Bluetooth Low Energy to a mobile device and uploaded to a cloud server for analysis [2].

Advances in microelectronics, low-power sensors, and IoT connectivity have enabled the development of nonintrusive health-monitoring systems that can be integrated directly into everyday objects. Smart home technologies increasingly rely on embedded systems and wireless sensor networks to provide seamless, continuous, and unobtrusive health tracking [4].

The literature on non-contact, non-intrusive vitalsign and sleep monitoring using piezoelectric sensors embedded in mattresses or pillows demonstrates promising feasibility. The work on mattress-based systems (Peng et al., 2019) [5] confirms that piezoelectric ceramic sensors can accurately detect respiration and heartbeat and that low complexity algorithms can support real-time monitoring.

Meanwhile, the intelligent pillow developed by Wang, Pang, Peng & Hu (2020) [6] provides a compelling proof-of-concept: a pillow that houses sensor, processing, and communication modules delivering high heart-rate detection accuracy and comfortable, non-intrusive monitoring for users. Agawane and Mudhalwadkar present a forward-looking approach with their design of a smart pillow aimed at detecting and managing snoring, addressing a common sleep issue [7]. Ravishani et al.'s IoT-based smart pillow aims to enhance sleep experiences through connected technologies, reflecting the growing trend of incorporating Internet of Things (IoT) in sleeprelated devices [8]. Ali et al.'s smart pillow for sleep apnea monitoring introduces a specialized device for managing a prevalent sleep disorder [9]. Veiga et al.'s IoT-based smart pillow for sleep quality monitoring in Ambient Assisted Living environments reflects the broader trend of integrating technology for improved healthcare in residential settings [10].

III. METHODOLOGY

The development of the IoT-based Smart Pillow Monitoring System for early stroke detection followed a structured process encompassing design, construction, testing, and evaluation. This methodology integrates engineering practices with user-centered evaluation to ensure both technical reliability and comfort for real-world use. A mixed-methods research design was employed, combining quantitative sensor data with qualitative user feedback. This approach allowed assessment of system performance while evaluating usability and comfort during sleep. The prototype was developed iteratively, selecting appropriate microcontrollers, sensors, and communication components. The IoT architecture spans from the sensing layer in the pillow to processing, connectivity, and application layers for real-time data analysis and display. Hardware integration focused on sensor placement for comfort and programming the ESP32 microcontroller to collect and transmit data. Software integration included firmware development, data filtering, and a user-friendly dashboard.

Data collection involved bench testing to validate sensor accuracy and responsiveness, followed by human testing in realistic resting conditions. Quantitative evaluation measured correlation, error rates, sensitivity, and specificity, while qualitative feedback assessed comfort, practicality, and user experience. Ethical considerations ensured participant understanding, data privacy, and adherence to safe, non-invasive health monitoring guidelines. Overall, the methodology demonstrates a balance of technical rigor and human-centered design, ensuring the Smart Pillow Monitoring System is both scientifically sound and practically applicable.

Recent studies have explored the use of smart pillows for non-intrusive health monitoring. Pandian et al. (2024) developed an IoT-based smart pillow that uses force sensing resistors to monitor head movement and sleep posture, transmitting data to healthcare providers for analysis [13]. Similarly, Wang et al. (2020) proposed an intelligent pillow using piezoelectric sensors capable of monitoring heart rate, respiratory rate, and body movement during sleep with high accuracy [17]. Other research by Li and Chiu (2018) focused on environmental and physiological monitoring using temperature and humidity sensors embedded in a pillow to analyze sleep conditions [14]. While these systems demonstrate the feasibility of pillow-based monitoring, most studies focus primarily on sleep quality or breathing analysis. Few systems integrate cardiovascular monitoring such as heart rate and oxygen saturation to detect serious health risks like stroke [15]. Therefore, this study proposes an IoT-based smart pillow system that integrates heart rate, SpO_2, and motion sensors to enable early detection of stroke warning signs [16].

A. Research Design

This study focuses on the design, development, and preliminary evaluation of a smart pillow system equipped with multiple sensors compatible simulation setup for MAX30102 using a potentiometer, buzzer, MPU6050, and a

mini microphone integrated with an ESP32 microcontroller. The system is intended to monitor three primary physiological indicators associated with possible early stroke warning signs: heart rate, respiration patterns, and body motion or immobility.

This study uses an experimental research design to develop and test an IoT-Based Smart Pillow System for monitoring heart rate, oxygen level (SpO_2), and body movement as possible early warning signs of stroke.

B. System Architecture

The system architecture of the IoT-Based Smart Pillow Monitoring System is designed to continuously collect, process, and transmit physiological data related to early stroke warning signs. The architecture follows a fourlayer IoT structure: detection layer, middleware layer, network layer, and service layer.

IoT-Based Smart Pillow Monitoring System

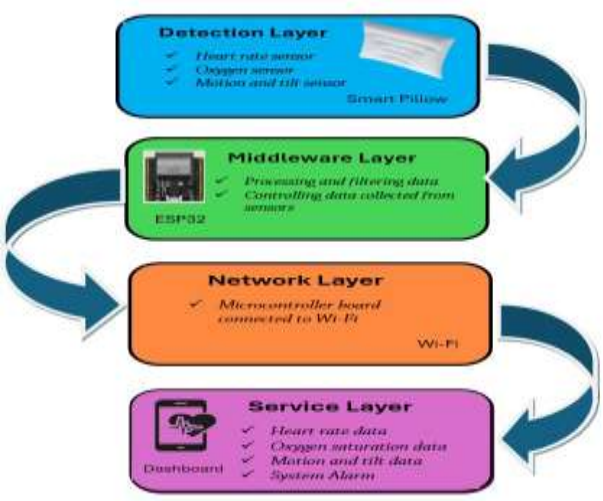

Fig. 1. The overall system architecture of the IoT-based Smart Pillow Monitoring System.

1. Detection Layer

This layer captures physiological and motion-related signals using embedded sensors integrated into the pillow. The MAX30102 sensor, simulated via a potentiometer in Wokwi, is used to represent heart rate and oxygen saturation measurements by generating variable analog signals. An MPU6050 accelerometer and gyroscope detect body movement, orientation, and sudden motion changes that may be associated with sleep disturbances or potential neurological irregularities. In addition, a piezoelectric sensor, if included, monitors respiratory movement by sensing pressure-induced voltage changes, providing supplementary data related to breathing patterns during sleep.

2. Middleware Layer

The ESP32 microcontroller is responsible for data acquisition, initial filtering, threshold-based anomaly detection, and wireless communication. Basic processing tasks include signal smoothing using moving average or low-pass filtering techniques, noise reduction to improve data reliability, detection of sudden spike or drop patterns that may indicate anomalies, and formatting of data packets for efficient transmission over the network.

3. Network Layer

Using Wi-Fi, the ESP32 transmits sensor data to a cloud server or real-time dashboard for monitoring. MQTT or HTTP protocols are used depending on system setup.

4. . Service Layer

A user dashboard, implemented using Node-RED, Firebase, or a custom web-based interface, visualizes the collected data in an accessible and user-friendly manner. It displays heart rate trends, oxygen saturation (SpO_2) levels, and motion indices over time, while also providing real-time alerts for abnormal physiological events to support timely user awareness and response.

This architecture allows the IoT-Based Smart Pillow Monitoring System to work seamlessly, combining accurate data collection, intelligent processing, and easy-to understand reporting for better sleep monitoring and early health warnings.

C. System Algorithm

. The IoT-Based Smart Pillow system continuously monitors a user's vital signs to detect early warning signs of stroke. It uses an ESP32 microcontroller connected to sensors that measure heart rate, oxygen saturation, and body movement. The system collects and filters data to remove noise, then checks for abnormalities based on set thresholds. If unusual readings are detected, it triggers an alert through a buzzer and sends notifications to a connected mobile app or cloud

platform. All data are stored in the cloud for monitoring and analysis. This process runs continuously while the user sleeps, ensuring early detection of potential stroke symptoms.

The core algorithm interprets real-time sensor inputs embedded inside the pillow, captures the data, and transmits it through Wi-Fi to the user interface.

Here is the pseudo-algorithm outline:
Start

Initialize ESP32 WiFi connection Initialize sensors:

- Heart rate & SpO2 sensor (MAX30102 / Potentiometer)
- Motion sensor (MPU6050)
- Microphone for sleep sound detection
- Buzzer for detecting abnormal irregularities

Collect real-time data
Read heart rate from MAX30102
Read oxygen level (SpO2)
Read motion data from MPU6050
Read sound data for abnormal snoring or sleep apnea from microphone.
Read and alert abnormal sounds from buzzer.

Process and filter data
Apply noise filtering to all signals Calculate averages or detect abnormal peaks
Extract features indicating stroke warning signs:
- Abnormally high/low heart rate
- Sudden drop in oxygen level
- Sudden body immobility or unusual movement
- Irregular breathing patterns

Decision-making
IF any value crosses danger threshold THEN It will set the status = "Warning: Possible Stroke Indicator"
And it will trigger buzzer or vibration alert
And if there's no abnormal irregularities
It will set the status as = "Normal"

Transmit data to cloud/user interface package heart rate, oxygen level, motion data.
Send data via WiFi to mobile app or dashboard

Display feedback
Update user interface dashboard.

End

This algorithm can be translated into a flowchart with four main layers:

The system architecture is organized into four functional layers. The **detection layer** is responsible for acquiring physiological and motion data, including heart rate, oxygen saturation (SpO_2), and body movement. The **middleware layer** performs data filtering, anomaly detection, and decision-making based on predefined thresholds. The **network layer** manages the transmission of processed data to cloud services or remote platforms, while the **service layer** delivers user-facing functionalities such as alert notifications and dashboard-based data visualization.

D. Implementation Details

The prototype will be developed using ESP32 microcontroller which integrates multisensory components including a simulation of MAX30102 in Wokwi using a Potentiometer as a placeholder for sensor reading for heartrate and oxygen sensor, a buzzer that alarms when detecting unusual movement, an MPU6050 accelerometer and gyroscope for motion and tilt detection, and a microphone module for detecting breathing sounds or abnormal nocturnal noises. A mobile or web -based dashboard will be developed HTML, Wokwi Application and Node-Red to display the heart rate, oxygen saturation level and alarm detection. Hardware will prioritize the availability, low maintenance and low power consumption. The IoT-based Smart Pillow Monitoring System is designed with user safety in mind.

E. Theoretical Foundations

The IoT-Based Smart Pillow Monitoring System is grounded in several key theories that explain how body signals are sensed, processed, and transformed into actionable health information for early stroke detection. IoT
Theory describes how objects become "smart" by integrating sensors, processors, and wireless communication, enabling the pillow to continuously monitor heart rate, oxygen levels, and motion while transmitting data in real-time to a mobile app or cloud platform for hands-free health monitoring. Cyber-Physical Systems (CPS) Theory emphasizes the interaction between physical signals and computational processes, allowing the pillow's sensors to capture physiological data while the ESP32 and cloud analyze it for real-time alerts and responsive actions to potential stroke indicators. Physiological Signal Theory explains how measurable signals such as heart rate, SpO_2, and motion reflect vital body functions, with pattern recognition enabling the detection of sudden changes or abnormalities that indicate stroke risk. Signal Processing Theory provides guidance on cleaning, filtering, and analyzing raw data, ensuring accurate and reliable detection of abnormal physiological patterns. Collectively, these theories form the

foundation of the smart pillow, detailing how it senses, processes, and interprets body signals to support early and reliable stroke detection.

IV. RESULTS AND DISCUSSION

This chapter presents the findings from the development, bench testing, and preliminary user evaluation of the IoT-Based Smart Pillow Monitoring System. The results focus on the system's ability to capture and process simulated physiological data, visualize trends through the dashboard interface, and deliver alerts based on thresholdbased anomaly detection. All findings are based on

prototype-level tests using simulated sensor inputs rather than clinical-grade measurements.

A. System Performance

Bench testing demonstrates that the ESP32 successfully handles multi-sensor inputs, including simulated heart rate and SpO_2 signals, motion readings from the MPU6050, and audio detection from the microphone. The microcontroller processes these inputs with minimal latency, applying basic filtering to reduce noise. The buzzer reliably activates when pre-defined thresholds are reached, validating the system's alert mechanism. Wireless data transmission to the cloud dashboard remains stable under normal network conditions.

B. User Comfort and Adaptability

Preliminary user evaluation indicates that the embedded sensors do not noticeably interfere with pillow softness or sleeping posture. Participants reported no significant discomfort during short-duration trials. The pillow's adaptability to different sleeping positions allows consistent monitoring, although sensor response varies slightly with extreme head positions due to changes in pressure distribution.

C. Data Monitoring and Visualization

The cloud dashboard effectively displays real-time heart rate, SpO_2, and motion data. Graphical visualizations enable users or caregivers to interpret trends easily. Alerts appear promptly when thresholds are exceeded. While the data accurately reflects the simulated inputs, small fluctuations occur due to noise and sensor simulation limitations, highlighting the need for more advanced filtering and calibration in future versions.

D. Limitations Observed

The prototype reveals several limitations that affect overall performance and reliability. Accuracy constraints arise from sensor simulation and potential interference caused by the pillow material, while reliance on Wi-Fi connectivity can disrupt real-time dashboard updates during unstable network conditions. The system is also sensitive to noise, particularly in the microphone and motion sensor readings, and measurement variability may occur due to differences in user posture and pressure distribution. These limitations indicate the need for improved hardware integration and more refined processing algorithms to achieve clinical-level reliability.

E. Overall Interpretation

Despite its limitations, the prototype demonstrates that embedding multi-sensor monitoring into a pillow is feasible and practical. The system achieves continuous monitoring, real-time alerting, and user comfort—all critical requirements for sleep-based stroke risk detection. The results support the potential for further development toward a fully operational smart health-monitoring device.

V. CONCLUSION AND RECOMMENDATION

The IoT-Based Smart Pillow Monitoring System demonstrates the feasibility of integrating multi-sensor health monitoring into a non-intrusive pillow format for continuous tracking of heart rate, oxygen saturation, and body motion. Prototype testing confirms that the system can capture simulated physiological signals, visualize them through a cloud dashboard, and deliver timely alerts without compromising user comfort. Although limitations exist—such as dependency on stable Wi-Fi, sensitivity to noise, and reduced accuracy due to indirect pillow-based sensing—the results affirm the potential of smart pillow technologies for accessible, home-based early detection of stroke-related warning signs. The system establishes a strong foundation for future development and contributes to ongoing efforts in IoT-driven health monitoring.

Several recommendations are proposed to enhance the effectiveness and reliability of the system. Sensor accuracy can be improved by integrating actual MAX30102 modules and applying more robust calibration methods. Wireless communication may be optimized through the use of more resilient IoT protocols or hybrid connectivity solutions to ensure stable data transmission. Refining the pillow design is also recommended to maintain consistent sensor contact across different sleep positions. The alert

mechanism can be enhanced by incorporating vibration motors, SMS notifications, or mobile application integration for improved user responsiveness. In addition, long-term testing under real sleep conditions is necessary to validate system reliability, and integration with medical platforms is recommended to support professional evaluation and strengthen preventive healthcare strategies.

In summary, the IoT-Based Smart Pillow Monitoring System represents an important step toward accessible, home-based health monitoring that does not rely on intrusive wearable devices. While the current prototype operates on simulated data and remains in the early stages of development, its performance demonstrates clear potential for future advancement into a clinically meaningful tool. Continued refinement of sensors, system responsiveness, comfort design, and data analysis methods will be essential in transforming this concept into a reliable early-warning system for individuals at risk of stroke. With further research and

development, the smart pillow can contribute to preventive healthcare, remote monitoring, and improved patient safety during sleep.

REFERENCES

[1] Centers for Disease Control and Prevention, "About Stroke," CDC, Oct. 24, 2024. [Online]. Available: https://www.cdc.gov/stroke/about/index.html

[2] S. Li and C. Chiu, "A smart pillow for health sensing system based on temperature and humidity sensors," Sensors, vol. 18, no. 11, p. 3664, 2018, doi: 10.3390/s18113664.

[3] E. Chiang and M. Vellaisamy, "Intelligent pillow for heart rate monitor," International Journal of Electrical and Computer Engineering (IJECE). [Online]. Available: [URL needed]

[4] American Heart Association, "Warning signs of a stroke," 2024. [Online]. Available: https://www.heart.org/en/health-topics/stroke/warningsigns-of-a-stroke

[5] A. Tubaishat, "IoT-based health monitoring systems: A review," International Journal of Advanced Computer Science and Applications, vol. 10, no. 6, pp. 80–89, 2019, doi: 10.14569/IJACSA.2019.0100612.

[6] M. Peng, Z. Ding, L. Wang, and X. Cheng, "Detection of sleep biosignals using an intelligent mattress based on piezoelectric ceramic sensors," Sensors, vol. 19, no. 18, p. 3843, 2019, doi: 10.3390/s19183843.

[7] W. Wang, Z. Pang, L. Peng, and F. Hu, "Non-intrusive vital sign monitoring using an intelligent pillow based on a piezoelectric ceramic sensor," Journal of Engineered Fibers and Fabrics, vol. 15, 2020, doi: 10.1177/1558925020977268.

[8] A. Agawane and R. Mudhalwadkar, "Design a smart pillow for detection and management of snoring," in Proc. 2023 IEEE 8th International Conference for Convergence in Technology (I2CT), 2023.

[9] W. M. S. Ravishani, et al., "IoT based smart pillow for improved sleep experience," in Proc. 2022 4th International Conference on Advancements in Computing (ICAC), 2022.

[10] A. Dos Reis, et al., "Smart companion pillow – an EPS@ISEP 2019 project," in Robot 2019: Fourth Iberian Robotics Conference: Advances in Robotics, vol. 2, Springer, 2020.

[11] S. Z. Ali, et al., "Smart pillow: Sleep apnea monitoring & minimization device," in Proc. 2019 7th International Conference on Robot Intelligence Technology and Applications (RiTA), 2019.

[12] A. Veiga, et al., "An IoT-based smart pillow for sleep quality monitoring in AAL environments," in Proc. 2018 Third International Conference on Fog and Mobile Edge Computing (FMEC), 2018

[13] Pandian, S. A. M., Sahil, S. M., Murugan, R., & Sakthi, M. K. (2024). An IoT-Based Health Sensing using Smart Pillow. *i-manager's Journal on IoT and Smart Automation, 2*(2), 26–31.

[14] Li, S., & Chiu, C. (2018). A Smart Pillow for Health Sensing System Based on Temperature and Humidity Sensors. *Sensors, 18*(11), 3664.

[15] Kumar, R., et al. (2024). IoT-Based Advanced Cardiac Arrest Detection System. *International Journal for Research in Applied Science and Engineering Technology (IJRASET).*

[16] Liu, Z., et al. (2025). An IoT-Enabled Smart Pillow with Multi-Spectrum Deep Learning Model for Real-Time Snoring Detection and Intervention. *Applied Sciences*

[17] Wang, W., Pang, Z., Peng, L., & Hu, F. (2020). *Non-intrusive vital sign monitoring using an intelligent pillow based on a piezoelectric ceramic sensor.* Journal of Engineered Fibers and Fabrics, 15.