International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 12 Issue: 03 | Mar 2025 www.irjet.net p-ISSN: 2395-0072

Cloud-Based IoT Coma Patient Monitoring System Utilizing Li-Fi Technology

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Abstract *- In intensive care environments, monitoring coma patients with precision and reliability is crucial. Utilizing Li-Fi technology and IoT for patient monitoring allows continuous tracking of vital signs such as heart rate, body temperature, oxygen saturation, and respiratory rate. By integrating Li-Fi with IoT, the approach enhances patient safety and ensures continuous, reliable monitoring, representing a significant advancement in healthcare technology. The system uses the Arduino Mega to collect vital data from sensors and the ESP8266 esp- 01 for fast wireless transfer. Data is streamed in real-time to ThingSpeak, a cloud platform for IoT analytics, for processing and analysis. The Prototypes effectiveness is validated across various lighting conditions. Integrating Li-Fi with IoT offers a robust solution for continuous monitoring of coma patients, significantly improving healthcare quality and safety.*

Key Words: **Remote health monitoring, LiFi, IoT, Cloud telemedicine, healthcare support.**

1. INTRODUCTION

Healthcare systems require continuous monitoring of critical patients, especially coma patients, who are unable to communicate their physical conditions. Manual monitoring of such patients is time-consuming, prone to human errors, and can delay emergency response. Traditional patient monitoring systems often rely on Wi-Fi-based communication protocols, which are vulnerable to electromagnetic interference (EMI) in hospital environments, posing risks to both patient safety and sensitive medical equipment. This creates a need for a reliable and automated patient monitoring system that provides real- time data without interference.

Li-Fi [1] technology, pioneered by Harald Haas in 2011, uses visible light for data transmission, emerging as a promising solution for healthcare systems. Unlike Wi-Fi [2], Li-Fi offers faster, secure, and interference-free communication, making it ideal for hospital environments. This project proposes a Cloud-Based IoT Coma Patient Monitoring System Utilizing Li-Fi Technology to continuously monitor patient vitals such as heart rate, oxygen saturation, temperature, and motion. The system integrates Li-Fi with IoT[3] to ensure seamless data transmission locally and remotely via cloud[4] platforms. Additionally, Li-Fi operates within the visible light spectrum (approximately 400 to 700 nm), which supports a broader frequency range (around 4×10^{14} to 7.5×10^{14} Hz) compared to Wi-Fi's microwave range (2.4 GHz to 5 GHz), allowing for significantly higher data rates and enhanced coverage in well-lit areas.

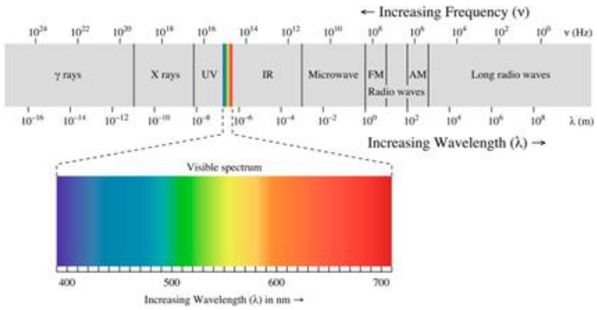

Fig -1: Electromagnetic Spectrum

The proposed model uses Arduino Mega 2560 as the core con- troller to interface multiple biosensors, including MAX30100 for heart rate and SpO_2, MPU6050 for motion detection, and DHT11 for temperature and humidity measurements. An ISD1820 module provides pre-recorded voice alerts, which are transmitted through LED light signals and received by a solar panel, establishing a sound-based Li-Fi communication link. Simultaneously, the ESP8266 - R1 Wi-Fi module uploads sensor data to the ThingSpeak cloud platform, allowing remote access to patient information. Developing an efficient monitoring system presents challenges such as ensuring continuous operation, reliable data transmission, and minimizing false alerts. The combination of Li-Fi and IoT creates a dual-alert mechanism, enhancing system reliability and response time. This hybrid approach aims to reduce healthcare staff workload while enabling faster and more accurate patient monitoring.

This paper presents the design, working methodology, and theoretical analysis of the proposed system, highlighting its potential to enhance patient care in healthcare environments. By leveraging the high-speed, interference-free nature of Li- Fi and the real-time data accessibility provided by IoT, the system ensures faster emergency responses and reduces the burden on healthcare professionals. Furthermore, the combination of cloud integration and dual-alert mechanisms ensures continuous monitoring, making it a reliable solution for critical patient care.

1.1 Literature Review

The integration of Light Fidelity (Li-Fi) technology in health-care has evolved progressively over recent years, addressing critical challenges in patient monitoring and data transmission. Initially, LiFi Experiments in a Hospital (May 2020) explored the feasibility of Li-Fi channel measurements in a neurosurgery room at Motol University Hospital, Prague. The study demonstrated the potential of multiuser MIMO Li-Fi links, showcasing achievable data rates and setting the stage for practical Li-Fi implementation in sensitive medical environments. This foundational work proved Li-Fi's capability to function reliably within hospital infrastructure. [5]

Building on this, Health Care Assistive System in Hospital (November 2022) introduced a more applied approach by replacing traditional Wi-Fi-based monitoring with a Li-Fi system. It highlighted Li-Fi's advantage in high-speed data trans- mission, even in dynamic environments affected by human movement. The system monitored clinical parameters such as temperature, pressure, pulse, hypoglycemia, and respiration, ensuring data was processed and displayed in real-time — reducing the manual workload on healthcare professionals. This marked a shift from experimental data studies to practical implementations in live hospital settings. [6]

Subsequently, Performance Evaluation of Smart Healthcare Monitoring System Using Li-Fi Technology (February 2023) advanced the concept by integrating Li-Fi with IoT to enable cloud-based monitoring. It demonstrated a dual-function system — transmitting vital signs like heart rate and temperature via Li-Fi to a central nurse station, while also uploading the data to ThingSpeak for remote access. Email notifications were incorporated to alert doctors during critical events. This system was successfully tested on patients at Imam Al-Sadiq Hospital, Babylon City, proving Li-Fi's robustness under various channel conditions and environmental noise. [7]

More recently, Lifi Enabled Cloud Based Health Monitoring and Menace Detection System for Wearable Devices (April 2024) expanded the scope to wearable devices, incorporating sensors for heart rate, temperature, gas detection, and blood pressure. It introduced secure, cloud-based data storage while maintaining real-time Li-Fi transmission to strategically placed receivers. The research emphasized the system's potential to enhance personalized healthcare by ensuring long-term data accessibility and improved security — a crucial step towards patient-centric, data-driven healthcare. [8]

Finally, Patient Health Monitoring System Using Li-Fi (June 2024) presented a cutting-edge model combining Li-Fi with Wi-Fi modules to create a hybrid, cloud-integrated monitoring system. It focused on real-time updates of health parameters, utilizing MEMS accelerometers and temperature sensors for continuous data collection. The system addressed practical challenges like manual monitoring fatigue by ensuring health data remains accessible to medical professionals remotely through the Ubidots cloud platform. This marked a shift towards intelligent, autonomous patient monitoring with reliable, interference-free Li-Fi communication. [8]

Collectively, these studies chart a clear trajectory — from initial feasibility experiments to fully integrated, cloud-based healthcare solutions. Each advancement addresses prior limitations, progressing towards faster, more secure, and accessible monitoring systems. Our Cloud-Based IoT Coma Patient Monitoring System Utilizing Li-Fi Technology builds directly on this foundation, incorporating real-time multi-sensor data col- lection, Li-Fi transmission, cloud storage, and alert systems to ensure continuous monitoring of coma patients — representing the next step in this technological evolution.

1.2 Problem Statement

Coma patients require continuous monitoring due to their inability to respond to stimuli. Wi-Fi-based systems and traditional manual inspections take a lot of time, are prone to mistakes, and are vulnerable to electromagnetic interference (EMI), which increases the chance of missing important changes. To guarantee accurate, continuous care and lower the stress on medical staff, a real-time, interference-free monitoring system is necessary.

2. METHODOLOGY

2.1 Arduino Mega Setup (Transmitter)

The Arduino Mega Setup serves as the core of the transmitter module. It integrates multiple sensors and modules to monitor patient vitals and trigger alerts when abnormal conditions are detected. The setup is explained below:

- Heart Rate and SpO2 Sensor (MAX30100 I2C): Is connected to Arduino Mega to continuously measure heart rate and blood oxygen levels. It helps detect low heart rate conditions for triggering the ISD module. Monitoring heart rate variability (HRV) is crucial for coma patients, as it reflects autonomic nervous system disturbances that may indicate seizures, a common complication in post- cardiac arrest cases. [9]

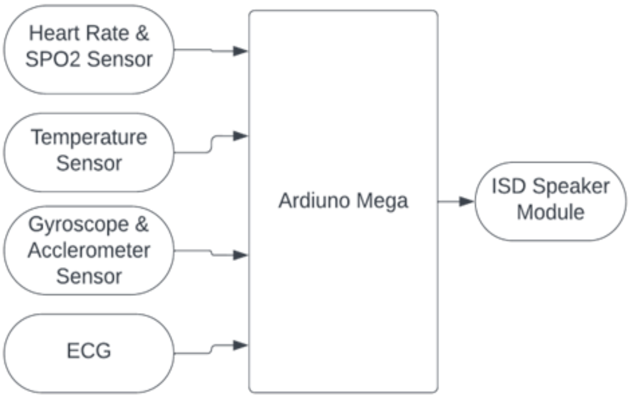

Fig -2: Arduino Setup

- Temperature Sensor (DHT11): Measures the patient's body temperature and sends data to the Arduino Mega for continuous monitoring.

- Gyroscope and Accelerometer Sensor (MPU6050): tracks the patient's body movements and orientation. It detects unusual movements or inactivity, contributing to the monitoring system.

- ECG(Electrocardiogram) Sensor: Records the electrical activity of the patient's heart, helping track cardiac health and identify any irregularities.

- ISD1800 Module: This device is triggered by the Arduino Mega when a low heart rate condition is detected. It plays a pre-recorded audio alert (" LOW HEART RATE") to signal an emergency.

- Microphone connected to the ISD1800 module receives the audio alert and transmits it via the Li-Fi transmitter, ensuring rapid communication to the receiver side for further processing.

This transmitter setup ensures continuous patient monitoring while incorporating an emergency alert system using Li-Fi technology for faster, interference-free data transmission.

2.2 Li-Fi Setup (Receiver)

The Li-Fi setup is designed to wirelessly transmit emergency alerts from the patient's side to the nurse station using light signals. The setup functions as follows:

- Microphone (Transmitter Side): It receives the audio alert triggered by the ISD1800 module and feeds the sound signal to the Li-Fi Transmitter module.

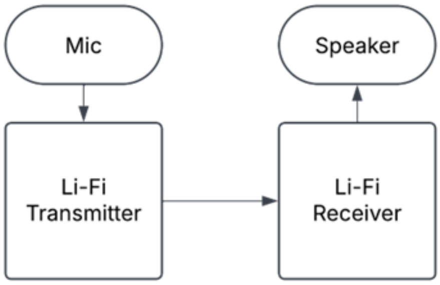

Fig -3: Li-fi Communication Setup

The Li-Fi transmitter converts the audio signal into light pulses using modulation circuitry. The sound is encoded into rapid variations in light intensity, where the LED acts as a light emitter. If the LED is ON, a digital signal '1' is transmitted; if OFF, a digital signal '0' is transmitted. Each LED light source functions as a hub for data transmission, enabling high-speed communication. [10]

- Solar Panel (Receiver Side): It captures the incoming light pulses and converts them back into electrical signals. This acts as a receiver (Photo-diode) for the light-based data.

On the receiver side, a photodetector (light sensor) captures the incoming light signals. It detects the LED's ON and OFF states, translating them back into binary data — '1' for light and '0' for no light. This process, combined with signal processing equipment, ensures accurate, high-speed data retrieval from the transmitted light beam. [10]

- Speaker: It is positioned at the nurse station which outputs the decoded audio alert, ensuring medical staff is promptly notified in case of an emergency.

This setup ensures fast, interference-free, and reliable data transmission using Li-Fi technology, enhancing patient safety and response time.

2.3 Result

The system was rigorously tested under various environmental and operational conditions to ensure consistent performance and accurate data transmission. The transmitter (Tx) side integrates multiple sensors — MAX30100 for heart rate and SpO_2, MPU6050 for motion detection, DHT11 for temperature, and AD8232 ECG sensor for heart activity monitoring. During initialization, the Arduino Mega processes incoming data from these sensors. To ensure the system starts properly, the LCD displays a welcome message:" Li-Fi Project," followed by" System Initializing." This ensures the user knows the setup is running. The ESP8266 R1 Wi-Fi module then attempts to establish an internet connection. A buzzer beep confirms a successful connection, ensuring data can now be transmitted to the ThingSpeak cloud platform for remote monitoring.

Once the system is fully operational, real-time sensor data is displayed on the 16x2 I2C LCD. The heart rate, temperature, SpO_2, and motion data update continuously. The ESP8266 - R1 handles cloud communication — fetching and pushing data to the cloud platform. This ensures data is not only available locally on the LCD but also accessible remotely by healthcare professionals, ensuring continuous monitoring from anywhere. The beep system helps confirm successful data transmission, reducing uncertainty in communication. This dual-layered data flow ensures that even if the cloud fails temporarily, the local LCD still provides live readings for immediate reference.

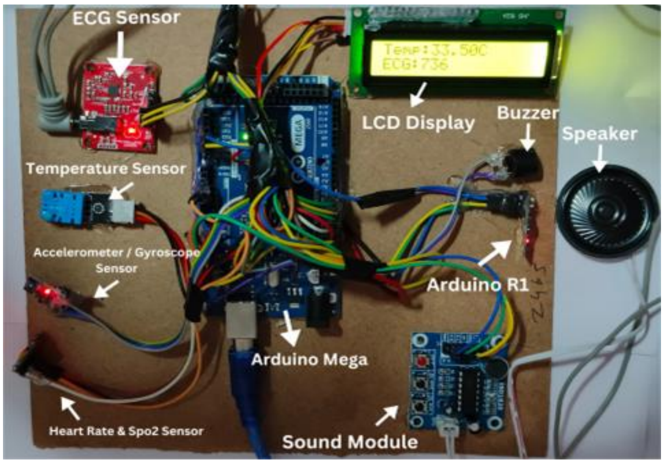

Fig-4. Arduino/Transmitter Setup

The alert system is a critical component designed to respond promptly to emergencies. If the heart rate falls below 70 BPM or the ECG sensor fails to detect any input — indicating a potential heart failure or lead disconnection — the LCD immediately displays" LOW HR!" as shown in the image. This visual alert ensures any nearby caregiver can quickly recognize the issue. Simultaneously, the ISD1820 voice recording mod- ule activates. It plays a pre-recorded message indicating the emergency, which is transmitted to a microphone connected to the Li-Fi transmitter. This innovative setup converts the audio alert into modulated light signals for wireless transmission.

Fig-5. Alert Message

On the receiver (Rx) side, the solar panel captures the in- coming Li-Fi light signal and converts it back into electrical signals. These signals are demodulated and passed to a speaker at the nurse station. The system ensures the alert is loudly announced, even if medical staff are away from the display or monitoring system. This ensures that the alert is not just confined to digital monitoring but also reaches human responders physically and audibly — a crucial redundancy in critical care environments where every second counts.

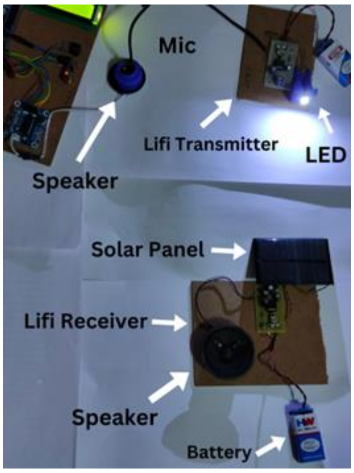

Fig. 6. Li-Fi/Rx Setup

The system's complete data flow follows a structured and reliable path:

1) Sensor data collected → Displayed on LCD (local feedback)
2) Sensor data → Pushed to ThingSpeak cloud (remote monitoring)
3) Low HR/No ECG detected → ISD1820 voice alert triggered
4) ISD1820 output → Microphone → Li-Fi transmitter →Solar panel (Rx)
5) Signal demodulated → Speaker at nurse station announces alert.

This multi-layered approach ensures maximum reliability — combining cloud-based remote monitoring with local physical alerts via Li-Fi technology. The system minimizes human error, enhances response times, and ensures continuous monitoring, providing a strong foundation for future medical alert systems in critical care environments.

The system utilizes ThingSpeak, an open-source Internet of Things (IoT) platform, to collect, store, and visualize patient data in real time. ThingSpeak supports up to 2 lakh data entries, providing ample storage for continuous monitoring over extended periods. It allows easy configuration of multiple data fields, enabling the display of various health parameters such as heart rate (BPM), SpO_2, temperature, motion (X- axis, Y-axis from MPU6050), and ECG readings. This data is plotted with time and date on the X-axis and correspond- ing sensor values on the Y-axis, offering a clear, dynamic visualization of the patient's vital signs. This helps healthcare professionals observe trends and identify anomalies over time.

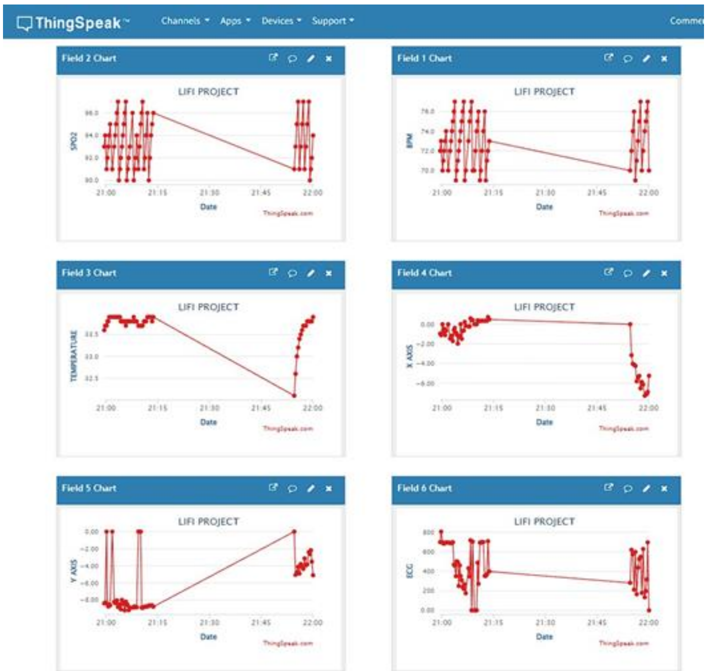

Fig-7. ThingSpeak Dashboard

The ESP8266 R1 WiFi module acts as the bridge between the sensors and the ThingSpeak platform. It communicates using HTTP GET requests, pushing data through ThingSpeak's API key. Each sensor's data is transmitted to its respective field in the cloud channel. After a successful connection, the module sends formatted data strings containing BPM, SpO_2, ECG, temperature, and motion values. ThingSpeak acknowledges each update, ensuring data integrity. The system also features a buzzer confirmation tone that triggers once data is successfully uploaded, adding an extra layer of reassurance that the data transmission is reliable.

ThingSpeak stands out from other platforms due to its simplicity, extensive storage, and advanced data visualization tools. It supports live charts, field averaging, and MATLAB analysis integration for deeper insights.

2.3.1 Observation Table

Sr. No	Patients (With Different Coma Condition)	ECG
1	Traumatic Brain Injury (TBI) Coma	211
2	Medically Induced Coma	462
3	Stroke-Induced Coma	354
4	Diabetic Coma	211
5	Anoxic Brain Injury Coma	719

Fig-8- Observation Table

The system was tested on different types of comatose patient scenarios, each reflecting unique ECG patterns and behavior.

For traumatic brain injury (TBI) and anoxic brain injury cases, ECG values showed irregular spikes, indicating moments of cardiac stress or compensation — a pattern missed by conventional heart rate (HR) sensors. Diabetic coma simulations produced low, steady ECG readings, matching the slowed heart activity caused by severe hypoglycemia. Meanwhile, stroke- induced coma scenarios displayed moderate fluctuations, reflecting the brain's partial loss of control over autonomic functions. Medically induced coma setups exhibited stable, controlled ECG outputs, supporting the expected baseline rhythm maintained during such procedures. The observation table documented how different coma types demonstrated distinctive ECG behavior, proving the need for continuous, type- specific monitoring rather than relying on generic pulse-based readings.

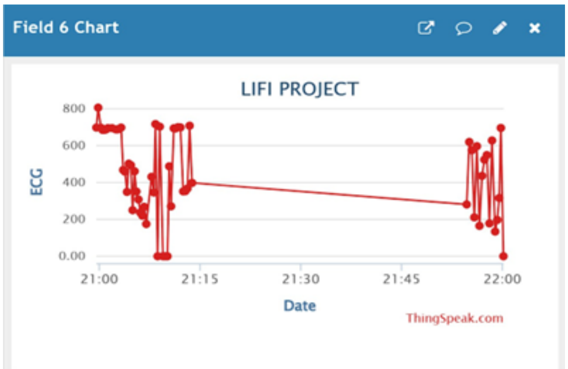

Fig-9. ECG Readings Of Different Coma Patients

ECG monitoring was prioritized over traditional heart rate sensors due to its higher accuracy and reliability. Arduino-compatible heart rate sensors like MAX30100 often vary in performance based on the manufacturer, leading to inconsistent readings under different conditions — especially when sensors fail to maintain skin contact. ECG, on the other hand, captures the heart's electrical activity directly, providing a more detailed and accurate representation of cardiac behavior. This ensures that critical changes, such as arrhythmias or flatlines, are detected instantly. The observation data supports this decision, showing that ECG outputs remained stable even when heart rate sensors produced fluctuating or false readings. This further validates the system's design choice to rely on ECG for real-time patient condition assessment.

3. CONCLUSION

The implemented results demonstrate that this technology holds significant potential for deployment in hospital environments, providing a safer alternative to traditional Wi- Fi by eliminating electromagnetic interference (EMI). The integration of Arduino Mega and Arduino ESP8266 - R1 for IoT functionality, combined with ThingSpeak as a cloud-based database for real-time monitoring, ensures efficient data handling and analysis. The Li-Fi system, acting as a reliable alert mechanism, ensures immediate notification at the nurse station, promoting faster response times in critical situations. Additionally, this approach enhances patient safety, particularly for those vulnerable to EMI, such as coma patients or individuals with pacemakers. With its low latency and high- speed data transfer, this setup lays the groundwork for more advanced, secure healthcare communication systems.

3.1 Future Scope

This project marks just the beginning of exploring Li-Fi technology in healthcare and beyond. Companies like Nav Wireless Technologies and group of professors in National University of San Juan, San Juan, Argentina have already demonstrated the potential of Li-Fi in providing connectivity solutions in rural regions and remote areas like Ladakh and Las Liebres (Small town in Argentina) respectively [11], where traditional networks struggle. Moving forward, Li-Fi could evolve from a specialized alert system to becoming the primary mode of data transmission in hospitals, enabling faster, safer, and interference-free communication for real-time patient monitoring, telemedicine, and even high-speed data sharing between medical devices. With advancements in Li-Fi hardware and infrastructure, the vision of an EMI-free, high- speed, and secure wireless environment across all sectors — from hospitals to smart cities — can become a reality.

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