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IoT-Powered Real-Time InPatient Monitoring System with Seamless Connectivity and Insights

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Abstract: IoT driven solutions for efficient and continuous patient monitoring is increasingly needed given that several resource limited and understaffed healthcare facilities require these solutions. In this paper, we describe a scalable and privacy respecting real time in-patient monitoring system coupled with a hybrid edge cloud architecture. The system is powered by an ESP32-C3 and the Gravity: MAX30102 heart and SpO_2 sensor, and a LM35 sensor for being body temperature. InfluxDB powered edge node is a node which processes sensor data using edge and then stores locally with low latency access and offline functionality. Also, the system synchronizes historical data to a secure cloud database as well as in sync to the database for analysis in advanced analysis and long-term trend monitoring. The real time dashboards and alert mechanisms that healthcare workers are empowered with, enables them to proactively take decisions as opposed to employing manual interventions. The system achieves performance, high reliability, and clinical utility for use in resource poor countries: an important step towards the development of cheap, automated vital tracking systems.
Keywords: IoT Healthcare, Vital Signs Monitoring, Edge-Cloud Architecture, Real-Time Patient Tracking

I. INTRODUCTION

Internet of Things (IoT) technologies have radically transformed the healthcare industry from a traditional one to the one that blends with the Internet as they increasingly find their way into clinical environments. One particular area that this shift benefits is inpatient vital monitoring, an essential but often hard limited process due to staff shortages, especially in developing regions like India. Traditional monitoring systems are manned intensive but likely to have slow response time and poor patient safety. These challenges emphasise the requirement of an automated, real time and scalable solution for monitoring vital signs without the burden of being an impediment to our healthcare staff.

In this paper a real time inpatient monitoring system is proposed that utilizes lightweight sensors connected in a wireless network to automatically measure and instantaneously transmit (stream) vital signs including heart rate, SpO2, body temperature and other parameters that are increasingly becoming well understood. In doing so, it introduces a hybrid edge–cloud model architecture wherein processed and visualised data in real time is stored at the edge to enable for real time knowledge and a month's trend is stored in the cloud safely. Affordable components such as ESP32-C3, Gravity: MAX30102, and LM35 sensors are taken advantage of by the proposed system to bring the resources within the constraints of the health care infrastructure to make things cheaper and further make clinical decision making better, with the data always available. This is a step in the right direction to delivery of accessible and intelligent healthcare monitoring in under resourced environments.

At the same time, the proposed system goes beyond providing the immediate clinical need, and takes into account the effects that data privacy, scalability and accessibility will have on the entire system. As compared with the traditional cloud dependent architectures which can suffer from issues of latency and connectivity, this system allows us to achieve uninterrupted operation and local control over the sensitive health data combined with an edge processing layer. However, this design also meets data protection standards and makes it easier to react swiftly and take localised decisions. Additionally, the cloud is scaled up by the cloud component and enables healthcare administrators to search historical data across many wards or facilities, making the allocation of resources better and also doing predictive healthcare analytics. Finally, the hybrid architecture of this architecture allows for a compromise between responsiveness, reliability and long term data utility, so that it is suitable for deployment in both urban and rural healthcare environments.

II. LITERATURE SURVEY

A study presented in [1] introduces an ECG monitoring system using the AD8232 sensor and ESP32 microcontroller. The data is transmitted using MQTT protocol to a webserver and mobile app. While the system ensures packet integrity with minimal data loss, it focuses solely on ECG signals and lacks broader physiological integration or analytical insights.

An extended work in [2] adds to this by including additional sensors such as temperature and pulse sensors in an Arduino-based design, with cloud integration through ThingSpeak and SMS alerts via GSM. However, this system is primarily reactive, relying on predefined thresholds and offering limited scope for advanced health diagnostics or intelligent alerting.

In [3], a performance-optimized IoT-based health system is developed with a similar ESP32-based architecture and MQTT communication. Though reliable, the study highlights higher network jitter over WAN and similarly emphasizes data reliability over system adaptability or clinical versatility.

A broader review presented in [4] classifies recent IoT health systems based on sensor types, network protocols, and their focus on data security and quality of service. Despite offering valuable taxonomies and performance insights, it lacks practical evaluation of these frameworks in clinical scenarios or their comparative real-world effectiveness.

An integrated solution is suggested in [5], which deploys a multi-sensor setup (ECG, SpO2, BP, PIR, temperature) connected via layered microcontrollers to a Wi-Fi-enabled cloud platform. Although highly accurate (with ~99% validation against hospital data), the system's complexity and reliance on cloud services raise concerns about feasibility in rural or low-resource settings.

In [6], an IoT-based smart health monitoring system is proposed to optimize service delivery in clinical settings. The system incorporates wearable sensors and cloud-based analytics to capture and assess patient vitals like ECG and SpO_2 in real-time. Although the design emphasizes scalability and smart alert generation, it remains highly dependent on constant internet availability and lacks provisions for edge-based data handling or offline functionality.

Reference [7] presents a comprehensive review of wireless healthcare monitoring systems, detailing the architecture of components such as sensors, transmission layers, and cloud backends. The authors highlight integration challenges and recommend modular designs to ensure future scalability. However, the paper leans more toward theoretical modelling rather than implementation-specific analysis, leaving questions around practical deployment and system reliability underexplored.

Study [8] focuses on the use of AI in medical systems, especially evaluating algorithms used in diagnostics and monitoring. Although not directly centred on IoT, it underscores the importance of reliable performance metrics and validation in clinical-grade applications. The study provides valuable criteria for assessing the success of systems like ours, particularly regarding accuracy and responsiveness.

In [9], the use of Bluetooth Low Energy (BLE) and iBeacon technology is explored for indoor healthcare tracking. This system is highly localized and effective for asset tracking and movement monitoring within hospital premises but does not focus on physiological data, limiting its application as a comprehensive health monitoring tool.

Reference [10] introduces a smartphone-based health monitoring system that integrates IoT sensors with mobile apps and cloud services. While the solution enhances accessibility and convenience for users, it is more geared toward outpatient or personal use rather than in-hospital monitoring, and lacks modular expansion or real-time alerting critical in inpatient care scenarios.

Collectively, these studies showcase the evolving landscape of IoT-based healthcare systems, highlighting their potential and limitations. While most frameworks effectively capture and transmit physiological data, many remain constrained by their reliance on cloud infrastructure, limited parameter tracking, or lack of intelligent edge processing. This reinforces the need for a hybrid system that not only ensures real-time monitoring and robust data handling at the edge but also provides scalable, privacy-conscious cloud storage—bridging the gap between feasibility, functionality, and clinical relevance.

III. PROPOSED METHODOLOGY

A hybrid edge-cloud IoT architecture for real time inpatient health monitoring is proposed and utilised in this system. The methodology consist of two-stages, firstly it acquires data with a Gravity: MAX30102 sensor for heart rate and SpO2, and LM35 sensor for body temperature. Preprocessing tasks like noise filtering and averaging of the sensor readings are handled by the ESP32-C3 microcontroller that is connected to an array of these sensors.

The data is first processed, and then sent to an edge node local InfluxDB instance in the case of analysing the data from within the same office or in the office house. For instant monitoring of the data for healthcare professionals, it is visualised in real-time on a local dashboard. A synchronisation service is also uploading historical data to a secure cloud database in a redundant, remote accessible, and long term analytics manner.

The system is comprised of a sensor data collection, an edge processing, a cloud synchronisation and a visualisation/alert system. Performance, reliability and fault tolerance are tested on each component. First of all, MQTT is used for lightweight data transmission in such a way that the system will work with low latency in the case of bandwidth constraint environments.

In designing this methodology, we try to strike a balance between clinical efficiency, data privacy, scalability, such that there exist continuous and reliable health insights in the healthcare setup in urban and rural environments.

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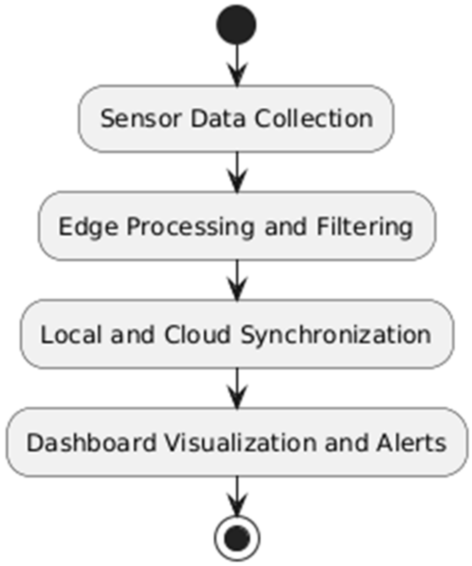

Fig 3.1 Methodology Flow Diagram

A. Sensor Data Collection

Sensor Data Collection phase is the sub project of hybrid IoT based health monitoring system. Once the vital signs are measured in this stage through onboard connected sensors to the ESP32-C3 microcontroller, physiological parameters are recorded. In this case, SpO_2 (blood oxygen saturation) and heart rate are measured by the MAX30102 sensor and body temperature is taken with the help of the LM35 sensor. Since these sensors are designed to be low power consuming, compact in size and medical grade reliable, they are chosen for continuous monitoring in both clinical and remote environments.

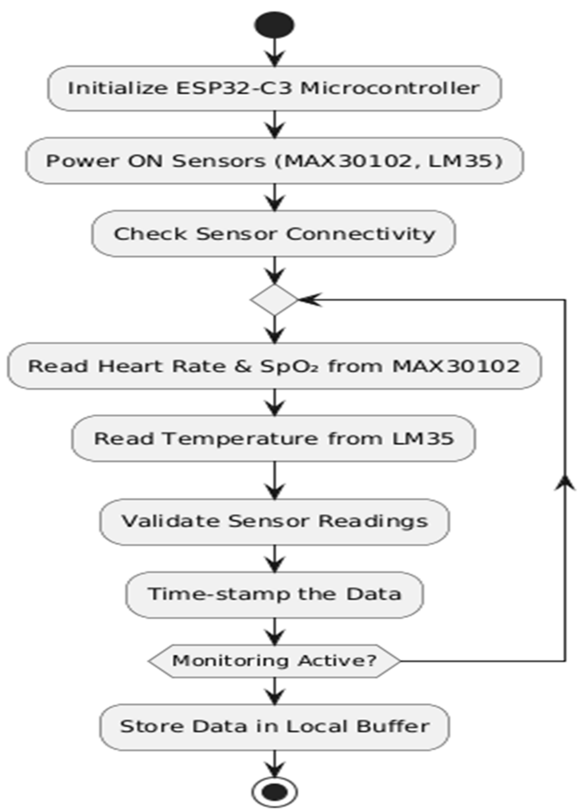

Fig 3.1.1 Sensor Data Collection Flow Chart

The ESP32 is interfaced electrically to each sensor and data is read at regular time intervals to make sure the data is being acquired in a consistent manner. UART, analogue input protocols are used to interface the microcontroller with the sensors. Timestamped, the raw data is put in memory until processed. The aim of this module is to be efficient, so as to have minimal power consumption and its latency to be very low, in order to keep the real-time tracking of health uninterrupted.

B. Edge Processing and Filtering

The Edge Processing and Filtering module takes large, overly abundant and noisy data and processes it down to only the clean, accurate and relevant data which needs to be transferred to the cloud or local dashboard. The raw sensor data is collected then preprocessing happens in the raw on the ESP32-C3 microcontroller. It entails cleaning the data through digital filter such as moving average or low pass filter 'noise', as well as validating data ranges in order to remove outliers and averaging values over time to minimize spikes and inconsistencies. Conducting these operations at the edge enables the system to bear little load on cloud services and reduce the band width consumption.

As well, edge processing facilitates more proximate decision making in the proximity of the data source. For instance, if the value of a patient's SpO_2 drops below a permissible limit or if the temperature is above fever level, the edge device can prompt instant alerts, and not require the cloud connection. In medical applications, such real time responsiveness is of paramount importance, whereas in areas with unreliable internet connectivity. The system integrates lightweight analytics and logic cheques at the edge while providing resilience, scalability, and accuracy in health insights with lower latency and a better reliability.

C. Local and Cloud Synchronization

The local and cloud synchronization module takes care of the smooth and secure interchange of patient vitals between the ESP32-C3 microcontroller and both local edge storage and the remote cloud database. Once collection and processing are performed on the sensor data at the edge, the sensor data is stored temporarily at a local InfluxDB instance. This design ensures that data is still available for visualization while network interruptions are ongoing and enables the collection and utilization of real time data for decision making at the point of care.

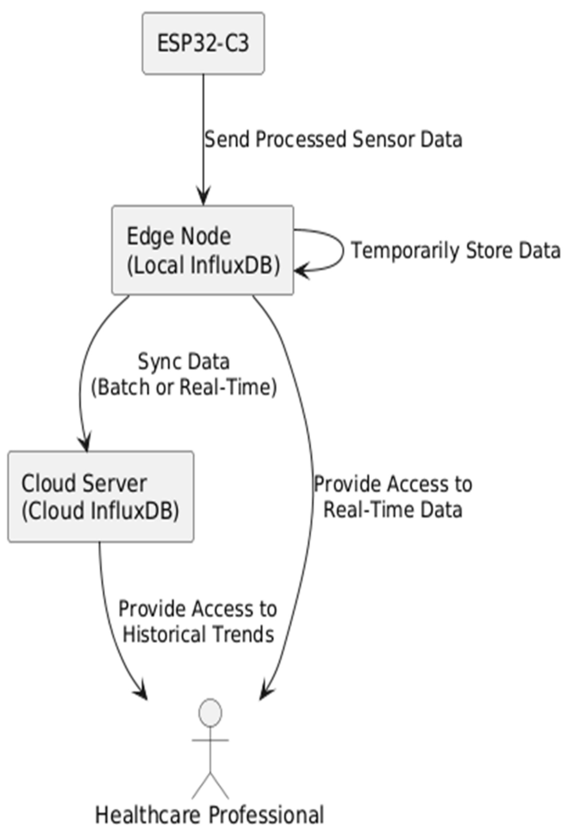

Fig 3.2.1 Local and Cloud Synchronization

Connecting to the local system securely in syncs the buffered data to an InfluxDB database hosted in the cloud. By doing so, these provide long term historical storage, advance analytics as well as remote access to healthcare professionals. It uses lightweight protocols such as MQTT or HTTP based on the conditions of the network, and performs batching of submissions based on time. The combination of dual layers in storage as well as local dashboards increases reliability, decreases latency for local visualisations, and enables centralised monitoring without compromising privacy or system performance.

D. Dashboard Visualization and Alerts

The purpose of the Dashboard Visualisation and Alerts module is to give healthcare patients an easy, real time way to monitor vitals including heart rate, SpO_2 and temperature. The dashboard is built in on the lightweight web technologies and data is fetched from the InfluxDB instances and presented as easy to understand graph and status cards. Current readings can be viewed, historical trends can be observed, and the health status can be checked quickly via colour codes. By visualising critical data, this helps make clinical settings quicker to react with more frequent decision making possibilities.

Another reason is that the system also has a solid alerting component, which sends out real time communication when any indispensable measurement exceeds a pre-determined criterion. Depending on the system config, these alerts can be sent via onscreen pop ups, emails or push notifications. The aim is to bring down response times of critical health events to the time and accuracy levels. It logs the alerts and its timestamp for traceability and medical review. Finally, this module has a dual role of informing medical staff in real time and feeding the data context for the correct patient care and early intervention.

E. Architecture Overview

The hybrid edge-cloud architecture is proposed for real time, continuous health monitoring in clinical settings, which follows a system configuration that loads applications and streamlines data in the cloud and utilizes servers to predict outcomes. The space for the system is a breadboard containing an ESP32-C3 micro controller along with biomedical sensors such as Gravity MAX30102 (heart rate and SpO_2) and LM35 (body temperature). Physiologically data being directly extracted from the patient and sent to the ESP32-C3 for local processing are gathered by these sensors.

Initial filtering and computation (like averaging or custom AQI-like health index) is handled by the ESP32, which publishes the data to a local InfluxDB instance over Wi-Fi to be used locally in a local dashboard. At the same time, some of the data is replicated or pushed for secure long term storage and global access to a cloud based InfluxDB node. The design makes sure that there is low latency access for real time interventions and high availability archival for diagnostics and analytics.

Depending on this also determines what the frontend interface will present — local networks will have live dashboards, where remote access only has historical insight. To compensate for resource constraints and to ensure reliability, privacy and clinical usability, features alert systems, performance optimization and fault tolerance mechanisms are included throughout the architecture.

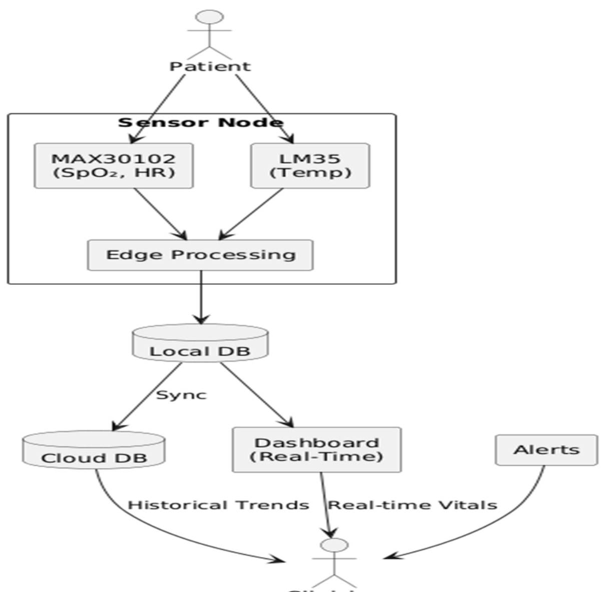

Fig 3.5.1 Architecture Diagram

F. Hardware Overview and Data flow

This hybrid edge-cloud health monitoring system integrates a set of hardware components to ensure uninterrupted acquisition, processing and transmission of patient vitals. The biomedical sensor system is composed of the ESP32-C3 microcontroller, with the MAX30102 for SpO_2 and heart rate and LM35 for body temperature being connected to it. Then, onboard filtering and averaging logic are used to filter and average the raw sensor readings to improve accuracy and reduce noise. At the same time, localized preprocessing guarantees real time responsiveness, while reducing the amount of transmission overhead in the resource burst healthcare environments.

The hybrid approach ensures data durability, therefore in case of a failure, the replication process just halts and it continues after recovery.

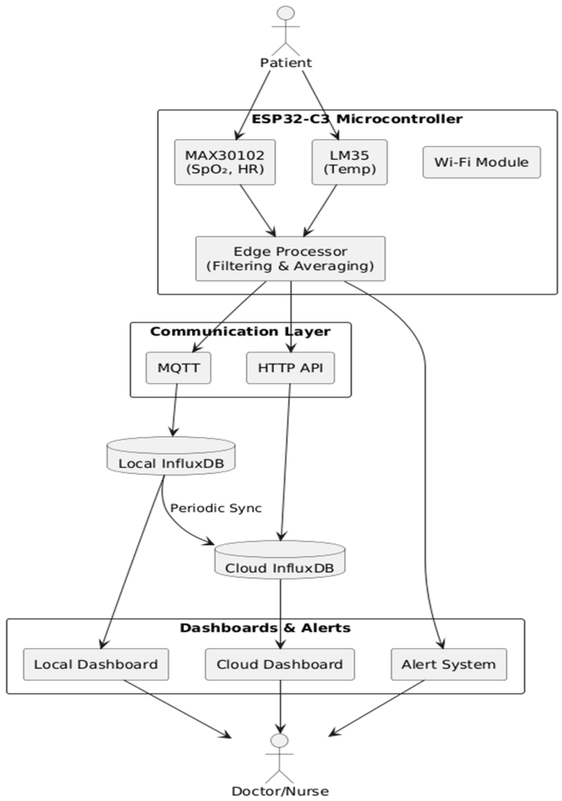

Fig 3.6.1 Hardware Overview and Data flow

The figure 3.6.1 shows the data flow through between sensors and the storage and visualization end points. It demonstrates how patient data is preprocessed at the sensor, gets translated from physical sensors to microcontroller, is communicated via MQTT and HTTP transports to a local InfluxDB instance, which synchronizes with the cloud database at regular intervals. Depending on the relevant context of access, dashboards will retrieve data from both a local and a cloud database when the network holds. In addition, the system also incorporates an alert function whereby healthcare professionals are notified in the case of abnormal readings. With this architecture, patient monitoring is both reliable, secure and scalable for current as well as historical trend analysis.

IV. RESULTS AND DISCUSSION

The implementation of the hybrid edge-cloud health monitoring system and the performance, reliability evaluation and clinical relevance attained was measured. The system achieved real time acquisition and processing of patient vital signs with low resolution including heart rate, SpO_2, body temperature. The ESP32-C3 microcontroller was able to accurately capture the data and transmit to the local or cloud database through either MQTT or HTTP protocol. It provided intuitive visualization in the dashboard and also notification within timing in alert mechanism. In this analysis, the results we got from system testing are highlighted and how the proposed solution improved the monitoring efficiency compared with the existing ways.

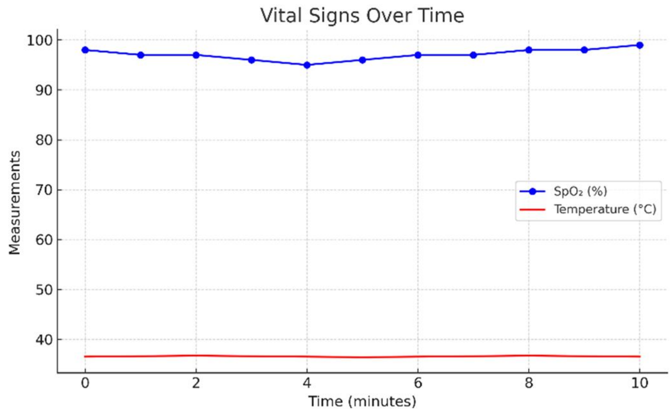

Fig 4.1 Trends in Patient Vital Signs

The graph displays the real-time data collected from the patient monitoring system, showcasing the heart rate, SpO_2 levels, and temperature over time. It visually represents how the system processes and monitors these vital signs, offering insights into patient health trends and the responsiveness of the edge-cloud architecture.

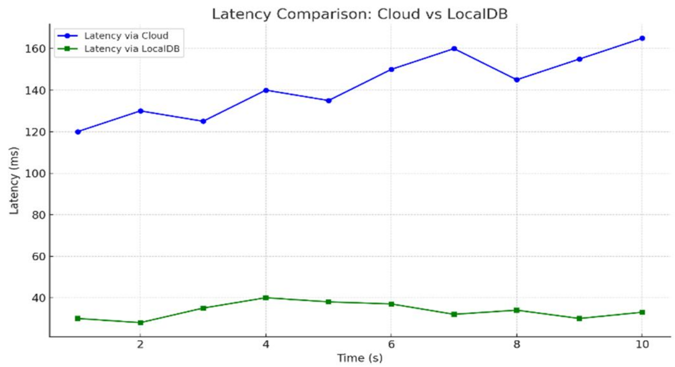

Fig 4.2 Latency Comparison CloudDB vs LocalDB

The plot above compares latency over time for two different architectures: CloudDB and LocalDB. The latency via cloud is shown in blue, while the latency via localDB is shown in green. As evident, cloud-based latency tends to be higher than the local database, highlighting the faster response times associated with edge processing. The results show that the proposed hybrid edge-cloud architecture can achieve a good balance of low latency local response lessness of secure and scalable cloud data retention. Acquiring and viewing critical vitals in response to an emergency can be done in a significantly shortened time with edge processing. At the same time, cloud synchronization occurs in periodic intervals in order to off load local resources and make historical data easily available for long term analysis. To demonstrate practical reliability, comparative latency graphs and accuracy validation confirm the system to be a viable solution for real time patient monitoring in both urban hospitals as well as the resource strained healthcare settings. In general, the findings provide evidence of how the system can help improve clinical workflows and patient safety.

V. CONCLUSION AND FUTURE SCOPE

The presented hybrid edge cloud health monitoring system fulfils the necessary of continuous and reliable patient monitoring in modern healthcare environments. Real time acquisition and preliminary processing of the most important vital health parameters namely heart rate and SpO_2, and body temperature is ensured by integration of the MAX30102 and LM35 sensors with ESP32-C3 microcontroller. Edge computing decreases latency dramatically, speeding up reply time in emergencies, and the cloud integration also fits in with storing and accessing remote data in the long run. The system has an efficient data flow, intuitive dashboards and is scalable, adaptable and user friendly. In comparison with conventional monitoring systems, it contributes to reduction of dependence on manual efforts and to the improvement of diagnostics through timely alerts and data-based insights. Thus, the system is shown as a robust solution towards improving inpatient care, particularly in resource constrained or highly burdened clinical environments.

However, future improvements can include the addition of additional sensors (ECG and blood pressure modules) to provide a wider scope patient's health profile. Edge AI/ML algorithms could incorporate predictive analytics permitting early sign predictions by clinicians as signs of deterioration; however, such algorithms would require fine tuning and resource planning for use by clinicians. Usability of mobile apps can also be enhanced by improving mobile app compatibility to be used on multiple platforms and to serve both patients as well as healthcare professionals. Additionally, it is possible to enhance privacy and security of handling medical data by using blockchain data encryption. Since the system is also used in rural or remote healthcare settings, expanding the system to support wearable devices and offline data caching will also make it more versatile and accessible.

That is in addition to interoperability with hospital EMR (Electronic Medical Records) systems, allowing clinical workflows to be streamlined. Further optimizing alert generation would be with automated anomaly detection and personally set threshold. OTA (Over the Air) mechanisms will also be used to update the firmware regularly. For the ICUs or elderly care homes, the solution can be extended to support multi patient monitoring hubs. Finally, it can be applied for large scale pilot study to validate its effect on various healthcare settings and to guide future improvements.

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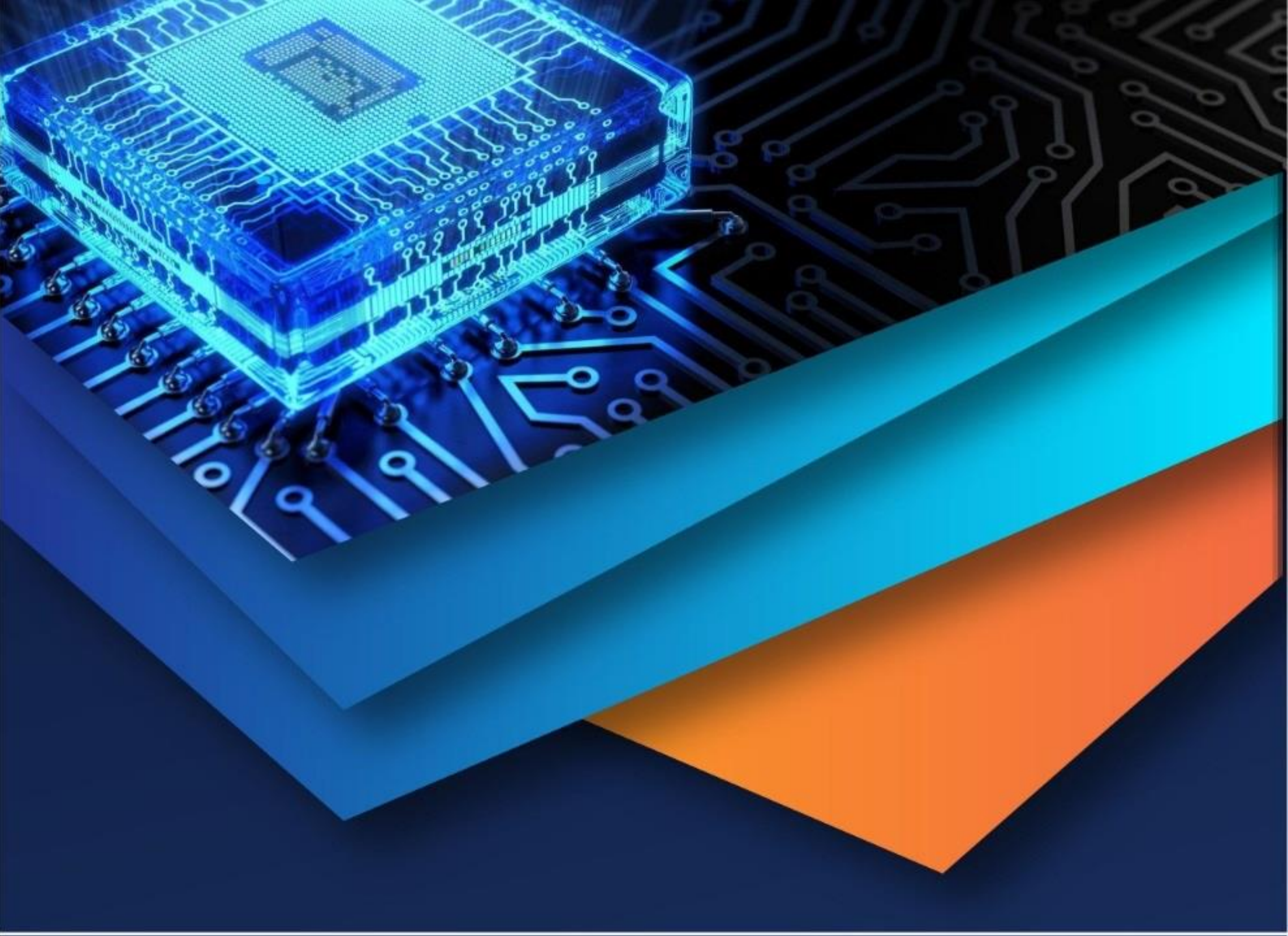

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