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RESEARCH ARTICLE

HARNESSING THE POWER OF IOT AND FOG COMPUTING FOR ENHANCED PATIENT MONITORING IN CRITICAL CARE UNITS

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Abstract

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In the realm of critical care, the need for precise and continuous monitoring of patients is paramount. This paper explores the development of an advanced system that leverages the capabilities of the Internet of Things (IoT) to facilitate the meticulous tracking of a patient's vital signs in Intensive Care Units (ICUs). The system is engineered to minimize the potential for human error by providing uninterrupted monitoring of various health indicators such as body temperature, blood oxygen saturation (SpO2), heart rate, blood pressure, and electrocardiogram (ECG) readings. Additionally, it can analyze patient fluids for glucose, lactate, blood circulation, red and white blood cell counts, as well as calcium and potassium levels. The system employs fog nodes as a means to store and process the data collected from patients. These nodes generate comprehensive health reports based on the collected data and store them in a cloud-based platform. This setup allows healthcare professionals, including doctors and ICU staff, to access real-time patient data and reports from any location at any time. The system is designed to alert the medical team in case of any detected anomalies in the patient's health parameters. This paper also provides a comparative analysis of previous research conducted on smart IoT devices used in ICU patient monitoring systems, highlighting the unique advantages offered by the proposed system. The paper concludes with a discussion on potential future enhancements, such as bolstering data security measures and incorporating machine learning techniques for improved system performance.

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Introduction:-

The provision of medical care is a fundamental necessity for all individuals. In the realm of patient care, technological advancements in the medical field play a pivotal role. Concurrently, there is a continuous global expansion in the implementation of Information and Communication Technologies (ICT) solutions within modern healthcare systems. Furthermore, the integration of Internet of Things (IoT) devices for medical treatment is viewed as a revolutionary Advancement in the healthcare sector. An integral component of the medical treatment landscape

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is the intensive care unit (ICU), which serves as a specialized and well-equipped area within medical facilities dedicated to the treatment of patients with life-threatening conditions and potentially recoverable injuries. The ICU is equipped with various essential devices such as patient monitoring systems, pain management tools, immediate resuscitation equipment, as well as respiratory and cardiac support devices, all intended for patients with severe injuries, life-threatening conditions, or those who have undergone major medical procedures necessitating round-the-clock care and support. ICUs, however, exhibit higher rates of mortality and morbidity compared to other healthcare settings. Studies have shown that a significant percentage of ICU patients experience medical errors, some of which lead to adverse health outcomes. Delayed identification of patients' deteriorating health due to monitoring errors is a common issue. Moreover, the substantial workload faced by ICU healthcare professionals has been linked to burnout. Addressing these challenges is crucial, and remote patient monitoring through IoT devices has emerged as a promising approach to enhance patient care. As per a recent study by KaaIoT Technologies, the investment in IoT-based healthcare solutions is projected to reach $1 trillion by 2025, offering tailored, accessible, and efficient healthcare services to a wide demographic. To address the aforementioned challenges, we propose an IoT-based ICU patient monitoring system. The contributions of this research encompass real-time monitoring and analysis of ICU patient health parameters using IoT devices, event classification based on fog computing for immediate response, and real-time alert-based decision-making with information delivery to medical practitioners and caregivers in diverse situations. This research is structured into five sections, including background research on relevant contributions, the methodology and operational principles of the proposed model, results and discussion, and the conclusion of the study.

Literature Review:-

In recent research related to our proposed system, several significant contributions have been made in the healthcare system and IoT fields, particularly in the area of ICU patient monitoring. Notable authors have proposed innovative IoT-based system architectures for the healthcare sector, with potential benefits in ICU, CCU, and ambulances. These proposed systems involve real-time intelligent monitoring, which can collect human body parameters data from various sources and analyze them. If any parameters exceed standard limits, the system can promptly send notifications to the Emergency Care Unit and relevant practitioners. Additionally, prototypes have been developed to continuously monitor ICU patients from home, aiming to constantly monitor vital signs and send alert messages to doctors in case of medical emergencies. These prototypes can also send patient health parameter data to centralized server systems for analysis and report generation. The authors of the paper [14] proposed an IoT-based system architecture for the healthcare sector, focusing on ICU patient monitoring and real-time intelligent monitoring system 1.

Another paper [15] developed a prototype for continuous remote monitoring of ICU patients from home, with a focus on monitoring vital signs and sending alert messages to doctors in case of medical emergencies. This research highlights the significant advancements in IoT-based systems for healthcare, particularly in ICU patient monitoring, and emphasizes the potential for real-time intelligent monitoring and continuous remote monitoring of patients. The author of the paper [16] devised a sophisticated healthcare monitoring and measurement system tailored to oversee a wide array of parameters (including ECG, oxygen level, humidity, temperature, and blood pressure) for Covid-19 patients requiring ICU care in hospitals. This high-level IoT cloud-based remote ICU patient monitoring platform aimed to extend the longevity of Covid patients by mitigating the inaccuracies inherent in human data processing. In a separate study, the paper [17] delineated the contemporary healthcare system named Smart ICU or EICU. This system integrated intelligent technology and sensors for health monitoring and diagnosis, displaying all patient parameters (Blood Pressure, SPO2, ECG) accessible to doctors worldwide through a simple cloud ID and internet connection. Moreover, it facilitated video calling with nurses or patients. The paper proposed an IoT monitoring system framework for ICU patients to enhance curative care delivery. It addressed the need for well-organized monitoring of various events and anomalies, including health conditions, non-vital events such as medicinal data and environmental and behavioral data, as well as dietary information of patients with temporal associations, culminating in a sensitive time alert generation system. Furthermore, the development and construction of a prototype monitoring system with low-cost, modular components were detailed in the paper [18]. This system, employing low-power sensors, aimed to expedite and improve treatment in critical situations. The IoT architecture was utilized to establish a RESTful-based Web interface, ensuring platform-agnostic behavior and offering a flexible mechanism for integrating new components. In a study detailed in the paper [19], an IoT application was introduced, leveraging a smartwatch to alert the assigned doctor in the critical unit. This wearable device enhanced the effectiveness of monitoring at-risk patients in hospital units by enabling medical doctors to access data at any time and from any location. A wireless network was established for bio-sensing platforms to detect metabolite concentrations in patients' fluids, transmitting the data to a smartwatch application. In cases of abnormal measured values, inbound alarm notifications were received, prompting immediate medical care. Another paper, [20], focused on developing a proficient healthcare IoT-based ICU Monitoring System that continuously measures the vital signs (such as temperature and pulse rate, etc.) of patients admitted to the ICU. This data is then sent to a dedicated website via the IoT system through a Wi-Fi module, allowing doctors to easily access their patients' data at any time from anywhere. Furthermore, the authors of the paper [21] concentrated on applying IoT in the healthcare system and proposed a novel architecture using an IoT concept under fog computing. This system was highlighted for its ability to provide real-time-based seamless health service in areas where the internet is not available or the internet connection is poor. It was also suitable for both patient monitoring and regular tracking of normal people's body parameters. In a separate study, the authors of the paper [22] designed a smart healthcare system architecture for monitoring critical patients in the ICU. This system could advise and inform doctors/medical assistants in real-time about changes in vital parameters or patient movement, as well as significant changes in environmental parameters, enabling them to take precautionary steps. These types of systems are beneficial to reduce the chance of human error caused by medical personnel such as assistants/nurses. The [23] study offers an e-health system based on the Internet of Things (IoT) and fog computing for monitoring geriatric health. The plan was created utilizing the Mysignals HW V2 platform and an Android app that serves as a Fog server, allowing for the collection of physiological and general health indicators from the elderly regularly. The elderly and their families can use this Android app to track their health, contact health care providers (administrators and doctors), and receive advice, notifications, and alarms. By assessing this system, we discover that the majority of users find it beneficial, simple to use, and learn, implying that our approach can increase the quality of aged health care. The authors of the paper [23] had only focused on measuring body parameters of ICU patients through IoT devices. In the article [24], the authors proposed a novel architecture to provide better security, privacy, transparency in the healthcare system for patients monitoring in ICU. They used blockchain technology and cryptographic methods to tamper-proof medical records and ensure data confidentiality. To reduce the communication latency in critical data processing, they used edge computing located inside the hospital. Constrained Application Protocol (CoAP) [25] and Datagram Transport Layer Security (DTLS) [26] protocol was used there to protect the precious sensor resources. In the study of paper [27], the authors proposed an IoT and machine learning-based framework to provide a better and smarter healthcare experience, especially while real-time monitoring critical patient’s conditions in ICU. They used blockchain technology to ensure the security of the framework. Utilizing fog computing reduced the communication latency and made the system more robust. MeDIC (Medical Data Interoperability through Collaboration) was proposed by the paper [28], as a system in which medical equipment collaborate to translate otherwise incompatible data formats. Registration, subscribing, probing, summarising, and publishing was all functions provided by the MeDIC framework. The observation was carried out to see how effective MeDIC was in terms of data response time and uplink traffic. The suggested framework is distributed scalable, and extensible to other aspects of protocol compatibility of IoMT and other IoT-related applications in general. In the study of this paper [29], the authors proposed a fog-assisted IoT-based patient health monitoring framework. Advanced techniques and services like as distributed storage and notification services and embedded data mining were employed at the network’s edge in their system. To analyze real-time data of the patient at the fog layer, and data transmission methodology based on event triggering was applied. The temporal mining technique was applied to assess the event’s adversities by calculating the patient’s temporal health index

The systems described are valuable in minimizing the potential for human error arising from medical personnel, such as assistants or nurses. In a study detailed in the paper [23], an e-health system based on the Internet of Things (IoT) and fog computing was presented for monitoring geriatric health. This system utilized the Mysignals HW V2 platform and an Android app serving as a Fog server to collect physiological and general health indicators from the elderly regularly. The Android app allowed the elderly and their families to track their health, communicate with healthcare providers (administrators and doctors), and receive advice, notifications, and alarms. The study found that the majority of users found the system beneficial, easy to use, and learn, suggesting that the approach could enhance the quality of aged healthcare. The authors of the paper [23] specifically focused on measuring body parameters of ICU patients through IoT devices. In another article, [24], the authors proposed a novel architecture to enhance security, privacy, and transparency in the healthcare system for patient monitoring in the ICU. They employed blockchain technology and cryptographic methods to secure medical records and ensure data confidentiality. To reduce communication latency in critical data processing, they utilized edge computing located inside the hospital. The Constrained Application Protocol (CoAP) [25] and Datagram Transport Layer Security (DTLS) [26] protocol were employed to protect the valuable sensor resources. Additionally, in the study detailed in paper [27], the authors proposed an IoT and machine learning-based framework to enhance healthcare, particularly in real-time monitoring of critical patient conditions in the ICU. They utilized blockchain technology to ensure the security of the framework and leveraged fog computing to reduce communication latency and enhance system robustness. Furthermore, the paper [28] introduced MeDIC (Medical Data Interoperability through Collaboration), a system in which medical equipment collaborates to translate otherwise incompatible data formats. MeDIC provided functions such as registration, subscribing, probing, summarizing, and publishing. An observation was conducted to assess the effectiveness of MeDIC in terms of data response time and uplink traffic. The framework was found to be distributed, scalable, and extensible to other aspects of protocol compatibility of IoMT and other IoT-related applications in general. In a separate study, the authors of paper [29] proposed a fog-assisted IoT-based patient health monitoring framework. Advanced techniques and services, such as distributed storage and notification services, and embedded data mining, were employed at the network's edge in their system. They applied a data transmission methodology based on event triggering to analyze real-time patient data at the fog layer and utilized temporal mining techniques to assess the adversities of events by calculating the patient's temporal health index.

In the paper [30], the focus is on IoT-based healthcare systems for cancer care and business analytics/cloud services, as well as the adoption and implementation of IoT/WSN technologies to complement existing treatment options and supply healthcare solutions. Business analytics/cloud services are positioned as enablers for actionable insights, decision-making, data transmission, and reporting to enhance cancer therapies. The paper also presents various frameworks and architectures to demonstrate and support the functioning of IoT-based solutions within the suggested smart healthcare solution for cancer care services. Additionally, it addresses the importance of understanding and addressing security and operational challenges within IoT-enabled healthcare systems. In the paper [31], the authors aimed to enhance the operational process of ICU monitoring in a private hospital in Jakarta by integrating IoT implementation with the Business Process Reengineering (BPR) approach. They utilized the Complex Proportional Assessment (COPRAS) method to prioritize the risks of the current monitoring process and proposed three business process models: 1. Intelligent Monitoring Analytics, 2. IoT-based Patient Monitoring, and 3. a combination of both. The research demonstrated that Scenario 3 (a combination of both 1 and 2) achieved a maximum process time reduction of 37.10%. Furthermore, the research article [32] reviewed IoT-based intelligent healthcare monitoring systems, highlighting their advantages and disadvantages, as well as common design and implementation patterns for patient monitoring systems. Additionally, a multi-purpose visual camera monitoring system, ADSA (Automatic Detection of Risk Situations and Alert), was proposed in the paper [33] for ICU patients.

Upon reviewing previous studies, it is evident that healthcare systems have not yet reached a satisfactory level, particularly concerning security and the performance of data storage. These studies have yet to specify how the concentrated features were selected. Additionally, simply utilizing traditional systems does not guarantee a model's suitability for practical implementation in the healthcare sector. Customization of the model is necessary to eliminate overfitting and expedite its application in a clinical setting. However, this research proposes an effective solution by integrating IoT with fog cloud to achieve a satisfactory level and assist doctors in the ICU in monitoring their patients. In conclusion, in an effort to delve into the motivations behind research, the author of this paper aims to enhance both the understanding and knowledge of healthcare evaluation. This research provides a summary of the findings and limitations of the previous studies, as depicted in Table 1 below.

Methodology:-

The section is divided into three interconnected segments. Firstly, it outlines the mechanism for setting up and monitoring the devices. Secondly, it delves into data collection and manipulation. Finally, it details the mechanism for real-time data monitoring by the assigned doctor(s) and ECU for further patient treatment. In step 1, the monitoring device will be set up in the hospital's ECU section, and an IoT device will be placed on the patient's body to facilitate real-time measurement of body parameters. Subsequently, the proposed device will collect all the parameters data and transmit it to the fog node for further processing. The fog node will generate a report based on the processed information and send it to the cloud for storage. In the final step, doctors can remotely monitor their ICU patients' data at any time and from anywhere using our proposed model. Additionally, our system will send notifications to the assigned doctor and ECU if any ICU patient's body parameters exceed the critical levels of standard body parameters. Furthermore, the planned architecture, comprising three layers. The first layer involves collecting the patient's body parameters using sensors to assess the patient's state. The second layer, consisting of fog nodes, processes all the data collected in the first layer, thereby reducing data latency. The final layer encompasses a cloud connected to the fog via a proxy server, responsible for long-term data storage. Our system will be connected to the internet via a proxy server, which will encrypt data before transferring it to the cloud storage. The proxy server will also act as web filters and firewalls, enhancing our system's security and preventing hacking. Moreover, our proposed model is divided into three modules: a. Setting & Checking Monitoring Devices (SCMD), b. Data Collecting, Processing & Storing (DCPS), and c. Real-Time Data Monitoring and Notifying (RTDMN). The subsequent section will provide a detailed description of these modules.

Discussion:-

Upon comprehensive literature review, it has become apparent that substantial work has been conducted on smart IoT devices for ICU patient monitoring systems. Specifically, papers [14], [15], [20], and [30] introduced IoT applications for estimating SpO2, blood pressure, temperature, and ECG, while paper [19] presented an IoT application for measuring metabolite concentrations in patients. However, some of these papers were only capable of measuring specific vital signs from the patients' bodies, while others could measure glucose and lactate from the patients' fluids. In contrast, our proposed system can measure a comprehensive range of parameters, including temperature, SpO2, heartbeat, blood pressure, ECG, glucose, lactate, blood circulation, red blood cells, white blood cells, calcium, and potassium from the patient's fluids. This represents a unique contribution to ICU patient monitoring systems, as no previous paper has measured all these parameters simultaneously. In contrast to the approach in the paper [18], which used battery-powered IoT devices for ICU patient monitoring, our proposed smart IoT ICU monitoring system will incorporate both wired and wireless facilities, eliminating the need for frequent recharging or battery replacements, thus reducing system downtimes and operational costs. Additionally, while the paper [34] described the use of cloud storage for collected data in the Smart ICU or EICU, our system will utilize fog nodes connected to IoT sensors to store real-time sensor data, reducing latency and enabling faster data access than cloud storage. This approach, incorporating fog nodes, represents a significant departure from the methodologies employed in very few previous papers and is expected to play a pivotal role in ICU monitoring systems. Furthermore, the use of fog nodes in our system will be augmented with a proxy server to connect to the internet, with data encryption and firewall protection to ensure data security. By avoiding direct connection to the internet, our system enhances security and mitigates the risk of data hacking. The analysis of simulated data reveals the significant contribution of sensor data to the automation of ICU and EICU, particularly in measuring the SpO2, heartbeat, and temperature parameters. Notably, our system is capable of measuring the normal, warning, and critical states of these parameters, as demonstrated in tables 3 and 4. Additionally, the fog computing-based scheme in our proposed system enables end-user devices to collaborate on processing, storage, and network communication tasks, thereby reducing latency and enhancing operational efficiency.

Conclusion:-

This study presents a smart IoT-based system designed for monitoring ICU patients, aiming to significantly reduce the risk of human errors during 24/7 continuous monitoring. The system is capable of monitoring various vital signs such as temperature, SpO2, heartbeat, blood pressure, ECG, as well as measuring glucose, lactate, blood circulation, red blood cells, white blood cells, calcium, and potassium in the patient's fluids. It has the capability to alert the doctor and ICU personnel in case of any detected abnormalities. Fog nodes are employed for storing and processing patients' data, generating reports based on various health parameters data, which are then stored in the cloud. Additionally, doctors and ICU personnel can monitor ICU patients in real-time and access their reports from anywhere, at any time. As part of future improvements, the study aims to enhance data security and incorporate machine learning techniques into the proposed system. Furthermore, efforts will be made to detect any blood clots in the ICU patients' veins and address specific related diseases. Experimental data has been collected and analyzed to achieve the objectives of the proposed model. The study asserts that the proposed system can effectively support real-time patient monitoring and facilitate the automation of cloud-based ICU operations.

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