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Review Paper on Automated Fluid Management in Healthcare using IoT

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***Abstract*— The manual monitoring of fluid management by nurses in hospitals still frequently leads to delays, fluid overflow, and even blood loss. These kinds of outcomes are caused by poor management, and the hospital has many beds. This study suggests an automated fluid monitoring system based on the Internet of Things to address these issues. Our system continuously monitors fluid levels and notifies nurses in real time, saving time and enhancing patient safety. In this research, a novel fluid bag monitoring method that works in both large urban hospitals and resource-constrained settings is presented. Through a comparison of current solutions and available literature, we demonstrate how automated IoT platforms transform hospital workflow and overcome management constraints associated with manual systems.**

***Index Terms*— Internet of Things (IoT), Fluid Monitoring, Healthcare Automation, ESP32, Real-Time Alert System, ESP NOW, MQTT, Patient Safety, Scalable Architecture, Rural Healthcare, Load Cell, Multi-bed Monitoring.**

I. INTRODUCTION

Hospital fluid management is a vital component of patient care since even minor errors can have a major negative impact on patients' health. Continuous patient monitoring is a duty for nurses, but they are unable to keep an eye on the fluid bags in time because of a shortage of hospital staff, particularly in rural regions. This results in fluid overflow, delays, and even blood loss. Hospital prices rise as a result of hospitals hiring more management staff. Following the expiration of the fluid bags, patients must call the nurses because there is a risk of blood spillage or a blocked vein, which can cause choking. In particular, night workers in hospitals are on duty at night, but occasionally they may fall asleep, which puts patients at risk. In order to address these ongoing problems, healthcare facilities are now anticipating an Internet of Things (IoT) based automated fluid monitoring system that can offer real time monitoring, lower patient risk, and work with the hospital management system. Microcontrollers will be used in the Internet of Things-based system to enable wireless connectivity. In addition to being affordable, these developments will offer benefits like usability, scalability, and dependability. The primary goal is not only to bring patients into a safe environment, but also to reduce the workload of nurses. Since nurses are unable to multitask, we are assisting them by offering this IoT-based solution that will be beneficial to them.

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After reviewing the current literature, we found that several of the methods and strategies are deficient, which results in problems with this system. Arduino-based control and SMS notifications are used to manage IV fluids in our foundation paper, "Design of Automated Control and Monitoring System for Intravenous Infusion Based on IoT" by Moovendan et al. We have determined that there are insufficient gaps that can be addressed by comparing with the base paper. As a result, our system uses a plug-and-play, reusable architecture that is appropriate for hospitals of all sizes as well as resource- constrained environments like medical camps and rural hospitals. The outcome is a fluid management strategy that is more dependable, scalable, and effective. It lessens the strain for medical personnel, improves patient safety, and even guarantees that hospitals, whether they are big cities or tiny rural clinics, can profit from this system.

II. LITERATURE REVIEW

One of the most important treatments in contemporary medicine is intravenous (IV) hydration therapy, especially for severely ill patients who need constant observation. Manual supervision by nurses or other caregivers is a major com- ponent of traditional monitoring. However, numerous studies have shown that manual saline monitoring is prone to errors, particularly in settings with heavy workloads. Serious complications could result from blood flowing back into the IV tube if the saline bottle empties and the needle is not quickly withdrawn. Researchers are investigating automated and Internet- of-Things-enabled monitoring methods because of this substantial clinical risk. Local alert methods were the mainstay of early saline monitoring systems. A buzzer-based device, for instance, was suggested by Priyadharshini et al. to alert nurses when the fluid reached a critical level. However, because they produce noise pollution and do not allow for remote mon- itoring, buzzer-based systems are inappropriate for medical settings. Similarly, systems that used GSM-based SMS alerts tried to enhance notice delivery; however, GSM has restricted scalability, higher operating costs, and a reliance on cellular networks. These constraints led to the need for more affordable, dependable, and Internet-based solutions. Wi-Fi-based

IoT systems are a better option, according to several researchers. Wi-Fi is inexpensive, widely available, and compatible with the hospital's current infrastructure. For continuous monitoring applications, Wi-Fi communication is less expensive than GSM, according to studies cited in Ghosh et al. To enable real-time monitoring using Wi-Fi, the sensing mechanism must be integrated with a microprocessor capable of wireless connection. To transform the mechanical deformation of the saline-filled bottle into a digital signal, Ghosh et al. used a load sensor in conjunction with an HX711 ADC. The accu- racy of load-cell-based assessment in identifying weight changes has been extensively tested, making it appropriate for monitoring fluid depletion. An ESP32 Wi-Fi microcontroller, a low-cost, low-power SoC widely used in Internet of Things applications, records the digital output. The ESP32 is perfect for continuous monitoring in healthcare settings because of its small form factor, low power consumption, and onboard Wi-Fi connectivity. For communication between devices, Ghosh et al. employed the MQTT-S protocol, a lightweight variant of MQTT developed for constrained IoT devices. Due to their large processing cost and increased bandwidth consumption, traditional protocols like HTTP are less effective. MQTT-S overcomes this issue by using topic IDs instead of topic strings, lowering payload size and boosting speed. The protocol also allows asynchronous communication utilizing a broker-based design, ensuring that subscribers such as doctors, nurses, and caregiver devices receive notifications reliably. For offline clients, MQTT-S can buffer messages, ensuring message delivery—a crucial function for healthcare monitoring systems. The methodology used in the paper is consistent with the larger trend in healthcare toward telemedicine and smart hospital systems, where IoT devices facilitate remote supervision and automate monitoring activities. The goals of smart healthcare systems are to eliminate human error, lessen staff work-load, and enhance patient safety. An important step toward real-time, affordable, and trustworthy saline level monitoring is the combination of ESP32, load sensors, and MQTT-S. All things considered, the studied literature shows a distinct pro- gression from basic alert-based systems to sophisticated IoT-enabled smart healthcare frameworks. The use of lightweight communication protocols, dependable message delivery methods, and the capacity to remotely monitor saline levels in real time make the Ghosh et al. study unique. These developments have a significant impact on the creation of safer and more effective healthcare monitoring systems. Paranthanman and Annalakshimi presented an IV fluid monitoring and control system based on the ESP32 that combines solenoid valve control with notifications from mobile apps. They focused on real-time clinical applicability, demonstrating how IoT devices can actively affect fluid administration rather than only pas- sively monitoring it. Similarly, IVigilance, a battery-operated multi-bed monitoring system with a central dashboard, was developed by Harshal Patil et al., showing a centralized approach to ward monitoring using IoT.

III. Proposed System

A. Introduction

Hospital fluid system monitoring by hand is a difficult and error-prone procedure. Nurses must promptly and routinely examine the fluid bags, which leads to repetitious checking that wastes time and raises the possibility of human mis- take. Partic ularly in rural regions with inadequate hospital administration this becomes an increasingly important issue. Complications for patients could include fluid overflow, inadequate flow control, or a delay in prompt medical attention. In rural hospitals and clinics with little resources, where a single nurse may be in charge of a large number of patients, the situation is much more dire. High patient loads, staffing shortages, and human exhaustion make it practically hard to ensure 24-hour monitoring for each fluid bag. Cases of fluid overflow, vein dislodgement, and delayed treatments continue to occur often despite the best efforts of medical personnel. We proposed an Internet of Things (IoT)-based automatic fluid monitoring system to get around these drawbacks. Our suggested method expands support for numerous healthcare fluids (IV drips, saline, blood, and urine bags), in contrast to previous systems that were restricted to IV fluids or solely depended on SMS-based warnings. This system uses a hybrid communication approach, utilizing MQTT to offer cloud-based storage, dashboards, and real-time warnings, and ESP-NOW to provide dependable local connection between repeater nodes and bedside devices. This method guarantees scalability among hospitals of all sizes, improves patient safety, and lessens the effort for medical personnel.

B. Objectives of the Proposed System

- Patient Safety First: By offering real-time monitoring and intelligent notifications that will automatically assure patient safety, we will guarantee patient safety. As a result, no patient will experience vein enlargement, air embolism, or fluid overflow.
- Reduce Nursing Burden: The nurses will not need to do round checkups so that they can work on other tasks. Nurses will get smart alerts on the dashboard and via the mobile application, indirectly reducing their burden.
- Universal Applicability:Make the system support mul tiple types of healthcare fluids, not only IV drips.
- Hybrid Communication reliability: Using ESP-NOW for low latency so that if internet connectivity is lost, data will be stored locally and uploaded to the cloud once connectivity resumes.
- Low-Cost Technology:Use affordable ESP32 hardware and load-cell sensors to make the system deployable in resource- constrained settings.
- Data Analytics: Store and analyse data for hospital audits, predictive alerts, and future medical research

C. System Architecture

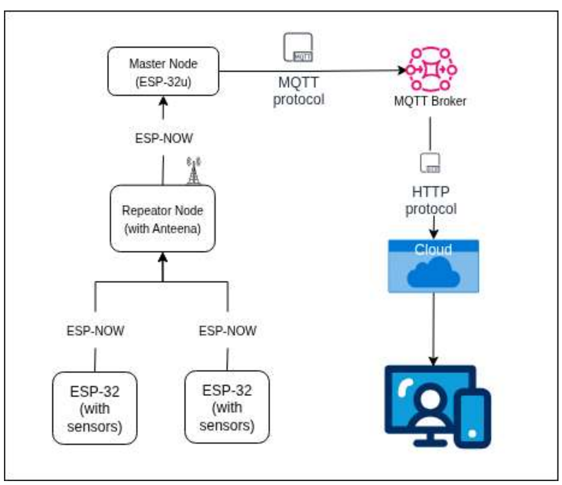

Figure 1: System Architecture of the Proposed IoT-based Fluid Monitoring

The architecture of the proposed system is designed to ensure modularity, reliability and scalability. The system is composed of four main layers: the Bedside Node, the Repeater Node, the Master Node, and the Cloud/dashboard with mobile application. At the first layer, closest to the patient, lies the Bed side Node. Each fluid bag—whether it contains saline, IV medicine—is placed on a load cell sensor. This sensor mea sures the weight of the bag, which directly reflects the re maining fluid volume. The sensor is interfaced with an HX711 amplifier to convert small analog signals into accurate digital values, which are then processed by an ESP32 microcontroller. Unlike earlier Arduino-based prototypes that were limited to wired setups and SMS notifications, the ESP32 provides powerful processing, Wi-Fi capabilities, and most importantly, support for ESP-NOW protocol. This enables fast, low-latency, and energy-efficient communication between devices. The bedside node is designed as a plug-and-play module: a nurse can simply attach it to a fluid stand, connect the bag, and the system automatically begins monitoring. The second layer is the Repeater Node, which is especially relevant in larger hospital settings where multiple wards or rooms need coverage. ESP-NOW communication works efficiently within a limited range, but hospital layouts often include thick walls, multiple floors, or long corridors. The repeater node solves this problem by acting as a bridge: it collects data from several bedside nodes and forwards it to the Master Node. This not only extends the communication range but also ensures that packet loss is minimized, a cru cial requirement in environments where missed alerts could endanger lives. At the third layer, the Master Node functions as the brain of the local system. It aggregates all incoming data from bedside and repeater nodes. Importantly, it operates in a hybrid mode: while it transmits data to the cloud via MQTT protocol, it also retains the ability to trigger local alerts (buzzers, LEDs, or alarms) in case of emergencies. This dual functionality ensures fault tolerance—patients remain safe even during internet outages, as local alerts will still be triggered by the master node. Finally, the fourth layer brings in the Cloud Server and Dashboard. Data sent from the master node is stored in a centralized database and processed for analytics. This enables real-time dashboards where nurses and doctors can monitor all patients in a ward from a single screen. The system also provides historical data storage, which is invaluable for hospital audits, medical research, and predictive healthcare (e.g., predicting when a fluid bag will empty based on past trends). A mobile app and web interface complement the dashboard, allowing staff to receive instant push notifications and monitor patient fluids even while moving across different wards. What makes this architecture human-centered is its careful balance between automation and accessibility. Instead of over engineering with high-cost cameras or AI systems that re quire constant internet, the design uses affordable sensors and proven IoT protocols, ensuring that even resource-constrained hospitals can adopt it. It reduces the burden on nurses without replacing their role; instead, it empowers them by ensuring they are notified at the right time, avoiding both medical risks and unnecessary manual checks.

D. Data Flow

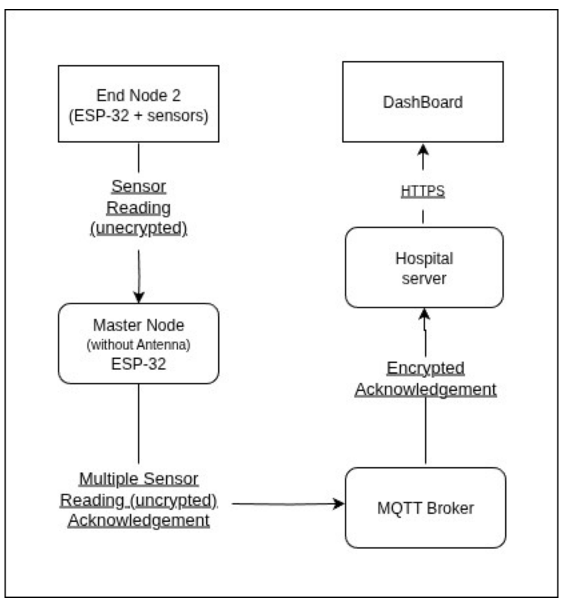

Figure 2: Data Flow Diagram of the Proposed System

The data flow — the lifeline that links the nurse's decision making with the patient's state — is part of the suggested system. This will guarantee that the system closely monitors each fluid level to guarantee patient safety — from a tiny drop to a critical threshold — and that data is recorded, sent, and 4 shared in real time.

Delays in healthcare can result in dire circumstances, so the data flow has been thoughtfully planned to be fault-tolerant, continuous, and simple to understand. As shown in Figure 2, the data flow can be broken down into six essential stages, each ensuring reliability at a different level of the system: Stage 1 — Fluid measurement at Bedside Node: A load cell sensor will continually weigh the fluid bag at the patient's bedside to begin the process. By using a built-in low-noise circuit to filter noise, the HX711 amplifier provides accurate digital signals to track even the smallest changes in fluid level. This assures consistent readings and records even the smallest drop in fluid volume. This input is processed by the ESP32 microcontroller, which also applies a calibration factor, filters noise, and prepares it for transmission. This implies that data is already accurate, cleansed, and patient-specific by the time it leaves the bedside. Stage 2 — Local Communication via ESP-NOW: ESP- NOW is a wireless communication protocol developed by Espressif Systems that allows ESP32 devices to communicate directly without requiring Wi-Fi routers or internet access. After processing, the ESP-NOW protocol is used to wirelessly transfer the data. ESP-NOW is well-suited to real-time monitoring because it allows direct device-to-device connection with ultra-low latency, unlike standard Wi-Fi. The bedside node connects directly to the closest Repeater Node or, if it is within range, the Master Node, negating the need for a router or internet access. This guarantees that data will always flow locally, even in settings with inadequate internet connectivity. Stage 3 — Repeater Node Forwarding: To increase communication range and guarantee dependable data flow, a repeater node is positioned between the master node and the bedside node(s). Not every bedside node can immediately reach the master node in a typical hospital ward because of numerous beds, walls, or long distances. The repeater node is crucial in this situation. By accepting data from many bedside devices and reliably sending it to the master node, it serves as a local traffic controller. The repeater can manage many-to-one communication and is small and energy-efficient. This design choice reflects hospital realities: equipment must adapt to building layouts rather than relying on flawless Wi-Fi connection in every ward. Stage 4 — Aggregation at Master Node: The master node is the central repository for ward patient data. It gathers incoming data, serves as a bridge between repeater nodes, and prepares it for cloud transmission. The master can quickly initiate local alarms (buzzers, flashing LEDs, or notifications on a nearby nurse's station computer) if it detects a fluid bag exceeding a critical threshold. This is significant since the master does not rely on the cloud to take action; even in the event of internet disruptions, local safety is preserved. Stage 5 — Transmission to Cloud via MQTT: The lightweight MQTT protocol — designed for constrained devices — is used to send aggregated data from the master node to the cloud. MQTT topics (for example, /ward1/patient05/fluidbag) provide structured message routing; dashboards and subscribed devices receive updates in real time. MQTT QoS levels help ensure message delivery reliability, even across intermittent networks. Stage 6 — Cloud Storage, Dashboard and Alerts: Data arriving at the cloud server is stored in an organized database. Analytics are performed to forecast bag depletion, display usage patterns, and preserve historical records for audits. Nurses' web dashboards and mobile apps receive push notifications and alerts. Fluid levels are displayed using clear indicators on a user-friendly interface, ensuring staff can quickly understand each patient's status even in high-stress situations.

E. ER Model

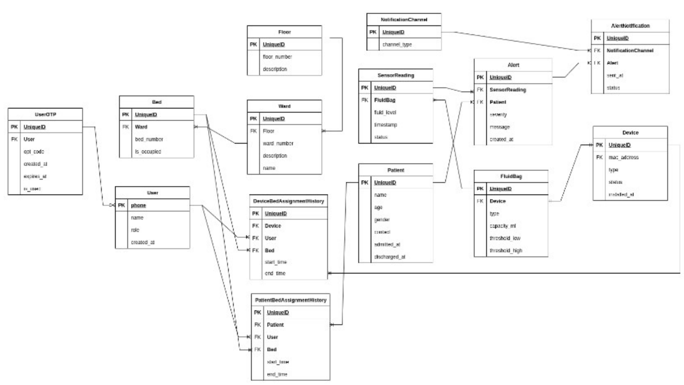

Figure 3: Entity-Relationship Diagram for the Proposed System

The ER diagram provides the backbone for the database de sign. It defines how different entities — patients, nurses, fluid bags, devices, and alerts — interact in hospital environments. The ER model mirrors actual hospital workflows, ensuring that every patient record, device reading, and nurse action is captured in a structured and traceable manner. Entity Attributes:

- Patient: PatientID, Name, Age, Bed Number, Ward
- Fluid Bag: FluidID, Type, Capacity, Threshold Level
- Bedside Device: DeviceID, CalibrationData, Status
- Alert Log: AlertID, PatientID, FluidID, Timestamp, AlertType, Status
- Nurse: NurseID, Name, Contact, Shift

F. Hardware and Software Components

Hardware Components

The proposed system relies on affordable and widely available hardware to ensure deployment in both large hospitals and resource-constrained clinics.

- ESP32 Microcontroller: Primary processing unit for bedside nodes; supports Wi-Fi, Bluetooth, and ESP-NOW.
- Load Cell Sensor: Measures the fluid bag weight with sufficient sensitivity to detect small changes.
- HX711 Amplifier Module: Amplifies load cell millivolt signals and provides 24-bit ADC precision.
- Repeater Node: ESP32-based node that forwards messages from bedside nodes to master to extend coverage.
- Master Node: Aggregates data and provides local alarms and MQTT bridging to the cloud.
- Power Supply: USB adapters or rechargeable power banks for bedside nodes; mains and UPS for masters and repeaters.

Software Components

- ESP-NOW Communication Protocol: Low-latency device-to-device messaging for local resilience.
- MQTT Protocol: Lightweight publish/subscribe protocol for cloud integration.
- Cloud Server: Centralized database and analytics engine; supports dashboards and notifications.
- Backend Application: Django/Node.js-based server managing authentication, data APIs, and analytics.
- Mobile Application / Web Dashboard: React Native and web dashboard for nurse access and push notifications.

IV. COMPARATIVE ANALYSIS

TABLE I: COMPARISON OF EXISTING APPROACHES VS PROPOSED SYSTEM

Author(s) & Year	Methodology	Strengths	Limitations	How Proposed System Overcomes
A. Paranthaman & K. Annalakshmi (2024)	ESP32 + load cell + solenoid valve; mobile app alerts	Real-time monitoring; modular design	Limited scalability; high energy consumption	Adds repeater nodes for multi-ward scalability; hybrid power supply options
H. Patil et al. (2024)	ESP32-based multi-bed monitoring with central dashboard	Supports multiple beds; centralized nurse monitoring	Short battery life; lacks predictive analytics	Integrates battery + mains backup; adds cloud-based predictive alerts
M. Moovendan et al. (2023)	Arduino + sensors; solenoid control; SMS-based alerts	Affordable; basic automation; fault tolerance features	SMS unreliable; IV-only; single-patient architecture	Replaces SMS with ESP-NOW + MQTT; adds multi-fluid and multi-bed scalability
W. S. Nimi et al. (2022)	IoT cloud monitoring for IV + vital signs	Holistic monitoring; reliable clinical alerts	High cost; requires continuous internet	Proposes hybrid communication (local + cloud) for rural reliability
D. Ghosh et al. (2021)	ESP32 + load cell; MQTT-S protocol	Lightweight; secure messaging; energy-efficient	Supports only saline monitoring	Extends support to IV, blood, urine, dialysis bags with same hardware setup
X. Bai et al. (2020)	IoT-based infusion monitoring deployed in hospitals	Clinically validated; practical real-world deployment	Expensive; limited scalability for large wards	Develops low-cost modular system scalable without major infrastructure changes
N. Giaquinto et al. (2020)	YOLO-based computer vision drip monitoring	Non-contact; AI-based high accuracy	Requires GPU/cloud; expensive; not suitable for rural areas	Uses low-cost sensors + ESP32 instead of cameras for rural affordability

V. Future Research Directions

- AI-Powered Predictive Monitoring: Current systems primarily detect critical fluid levels and send alerts. Future sys- tems should incorporate machine learning models that can predict when a bag will deplete based on patient consumption patterns and historical data. Predic tive models could even adjust for patient condition (e.g., faster fluid consumption in high-fever cases), helping nurses plan proactive interventions.
- Integration with Hospital Management Systems: In tegration with Electronic Health Records (EHRs) and Hospital Information Systems (HIS) will enable seam less patient dataflow across departments and automatic task creation for nursing/pharmacy workflows.
- Enhanced Data Security and Privacy: Healthcare data is sensitive; future systems should consider end-to-end encryp- tion and role-based access, and compliance with standards such as HIPAA or NDHM.
- Ultra-Low Power IoT Devices: Further optimization for battery life to reduce maintenance overhead in resource limited settings.
- Edge and Fog Computing: Move simple analytics to edge/fog nodes (bedside or repeater/master nodes) to reduce cloud dependency and latency.
- Expansion to Other Domains: Adapt system design to monitor infusion pumps, oxygen, ventilators, and other critical resources.
- AIoT for Smart Hospitals: Combine computer vision and sensors for anomaly detection (blockages, leaks, dislodge- ment) that sensors alone might miss.

VI. Conclusion

In the end, healthcare is about people: nurses who are responsible for keeping patients safe and patients who entrust hospitals with their lives. Something as seemingly straightfor ward as a fluid bag can rapidly escalate into a life-threatening situation if ignored. This assessment emphasized how staffing shortages, fatigue, and growing patient loads continue to be problems for hospitals, particularly in rural and resource constrained areas, regarding manual fluid monitoring. In response, researchers have developed a variety of tech nical solutions over time, ranging from cloud and AI-driven monitoring to Arduino SMS-based alerts. Each approach of fered lessons and also revealed gaps: restricted scalability, reliance on SMS or continuous internet, high deployment costs, or limited focus on IV fluids alone. Our proposed hybrid system — combining low-cost ESP32 hardware, load-cell sensors, HX711 amplifiers, ESP-NOW for local resilience, and MQTT for cloud integration — aims to be fault-tolerant, multi-fluid compatible, scalable, and affordable, suitable for both urban hospitals and rural clinics. It reduces nursing workload, improves patient safety, and provides a foundation for future predictive and integrated hospital sys tems.

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