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Intra Venous Fluid Monitoring System Using Infusion Pump Mechanism

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***Abstract*— Hydration and electrolyte management are essential for patient care, especially in intensive care units, where hospitals traditionally rely on manual checks, which can lead to errors. For example, forgetting to replace a drained IV bottle or allowing fluid to continue flowing after it's empty can result in air bubbles or reverse blood flow, both of which can be fatal. To address these issues, an advanced IV fluid management system can integrate a force plate sensor at the bottom of the IV fluid bottle, which detects when the fluid level is low and triggers a cut-off switch to halt the flow, preventing further complications. Additionally, a smart infusion mechanism ensures accurate and controlled fluid delivery. The system is connected to a mobile application that allows caregivers to monitor the patient's fluid and electrolyte levels in real-time. Alerts are sent to caregivers or charge nurses if electrolyte levels drop below safe thresholds, ensuring no critical delays and improving patient safety by preventing life-threatening situations. The system can also provide real-time data on fluid infusion rates, enabling healthcare professionals to adjust the treatment based on the patient's needs. By automating fluid monitoring and providing real-time notifications, this system minimizes the risk of air bubbles or reverse blood flow, significantly enhancing patient safety, reducing human error, and providing a more efficient, responsive approach to IV fluid management. Furthermore, the integration of IoT technology ensures that caregivers have immediate access to accurate data, improving decision-making and allowing for prompt interventions when needed.**

Index Terms*—Hydration, Electrolyte Management, IV Fluid Management, Force Plate Sensor, Cut-Off Switch, Infusion Mechanism, Real-Time Monitoring, Mobile Application, Alert Notification, Patient Safety, Human Error Reduction*

I. INTRODUCTION

The primary goal of this project is to develop an intelligent, automated, and cost-effective intravenous (IV) fluid monitoring and automatic cut-off system, leveraging advancements in embedded electronics, sensor technology, and Internet of Things (IoT) integration. The system is designed to continuously track the weight of the IV fluid using a force plate load cell sensor connected through an HX711 amplifier, providing precise measurements that inform the system about the current fluid level.

To maintain a sterile and accurate flow of IV fluids, a peristaltic pump is employed. This pump type is particularly beneficial in medical applications due to its non-invasive nature it avoids direct contact with the fluid and reduces contamination risk, making it ideal for sensitive healthcare environments. Complementing this is the integration of a solenoid valve, which functions as a real-time safety mechanism. The valve responds to signals from the microcontroller to either allow or stop the fluid flow based on the weight data, preventing issues such as air embolism or reverse blood flow.

At the core of the system lies the ESP32 microcontroller, chosen for its dual functionality: powerful edge computing capability and built-in Wi-Fi connectivity. The ESP32 processes data from the sensors, makes logical decisions regarding pump and valve control, and transmits critical system status or alerts to a remote monitoring platform. This cloud-enabled communication allows healthcare providers or caretakers to receive real-time updates on fluid status, significantly reducing the risk of human error and enabling timely interventions.

Additionally, the system includes an OLED display for local data visualization and a buzzer for audio alerts in emergency conditions. Its modular and scalable design ensures it can be adapted for various use cases, including hospital wards, ICU units, ambulatory care, and even home-based patient monitoring in rural areas where access to continuous professional care may be limited.

This integrated, smart IV fluid system thus represents a comprehensive solution that enhances patient safety, reduces manual workload on medical staff, and brings affordability and automation to a critical aspect of healthcare delivery.

II. LITERATURE REVIEW

Intravenous (IV) fluid monitoring and control have become critical aspects of modern healthcare, particularly in ensuring the safe and accurate administration of fluids to patients. The need for precise management of IV fluids arises from the potential risks associated with incorrect dosage, flow rates, or interruptions in the infusion process. In recent years, technological advancements have led to the development of various systems aimed at improving the accuracy, safety, and efficiency of intravenous therapy. These systems incorporate a range of sensors, automation mechanisms, and machine learning algorithms to monitor fluid levels, detect potential issues such as over-infusion or reverse flow, and take corrective actions when necessary.

Various sensor technologies such as capacitive, pressure, and flow sensors are explored, alongside the integration of wireless communication and real-time monitoring for enhanced patient safety and operational efficiency. The review also highlights the challenges faced in developing reliable, low-cost, and accurate fluid infusion control systems, along with the potential for future advancements in this domain.

Anholt et al. (2010) explored the relationship between Autism, ADHD, and Obsessive-Compulsive Disorder (OCD), emphasizing the need for accurate symptom identification in mental health. Although not directly related to fluid infusion systems, this research highlights the importance of accurate monitoring in healthcare settings, an approach that can be extended to IV fluid management. Their work emphasizes the need for better diagnostic and monitoring systems in health settings, which can inspire the development of automated infusion technologies that provide more accurate and real-time information for patients with critical health conditions like those requiring IV fluids [1].

Bai and Han (2023) proposed a fuzzy evaluation-based mental health assessment system that uses intelligent evaluation methods to improve patient monitoring. This concept of automated assessment and real-time feedback could be applied to IV fluid management, where real-time alerts and accurate monitoring are essential to prevent complications such as air bubbles or reverse blood flow. This work supports the idea that intelligent systems can significantly enhance patient safety [2].

Cataldo et al. (2012) conducted studies on microwave TDR (Time Domain Reflectometry) for real-time monitoring of intravenous drip infusions. Their research demonstrated the potential of microwave-based sensors to provide continuous and precise monitoring of IV fluid flow. This innovative approach presents a viable alternative to traditional manual monitoring methods, offering the ability to track and manage IV fluid levels with high accuracy. These findings are directly relevant to enhancing the precision of IV fluid delivery systems, especially in high-risk environments such as neonatal and ICU care [3]

In 2012, Cataldo A., Cannazza G., et al. further explored the application of microwave TDR for intravenous fluid management, showcasing its ability to monitor and control fluid delivery in real-time. Their research demonstrated that TDR systems could effectively address common issues in intravenous therapies, aligning with our project's aim of improving patient safety through automated fluid monitoring [4].

Correia et al. (1981) introduced a portable device designed for measuring regional cerebral blood flow in intensive care units (ICU) and operating rooms (OR). This research highlights the importance of real-time monitoring in critical care settings. The principles of real-time measurement and monitoring discussed in this study can be applied to the development of IV fluid monitoring systems to enhance safety during fluid administration, particularly in high-risk clinical scenarios like those requiring constant fluid delivery [5].

Furutani, Araki, and Maetani (1995) explored blood pressure control during surgical operations, offering insights into maintaining precise control over patient conditions in high-stakes environments. Their work is relevant to IV fluid management as it emphasizes the importance of tight regulation of fluid delivery to avoid adverse outcomes such as excessive fluid buildup or insufficient flow [6].

Giaquinto et al. (2021) investigated deep learning-based computer vision for real-time IV drip infusion monitoring. They applied artificial intelligence (AI) techniques to detect abnormalities in fluid infusion, which could lead to complications. This AI-based approach for monitoring fluid infusion is a promising advancement, particularly when combined with sensors like load cells or other flow detection methods. The study underscores the potential for using machine learning and AI to enhance the precision of fluid management in hospitals, making it a key reference for any project focused on automated IV fluid monitoring [7].

Gorelova et al. (2024) conducted a simulation study in assisted reproduction clinics and integrated a smart health monitoring system into the process. Their findings demonstrate the value of integrating advanced technology for monitoring patient health in real-time, which is directly applicable to the healthcare domain of IV fluid management, particularly in terms of integrating sensor systems with healthcare infrastructure for immediate feedback and alerts [8].

Janokar et al. (2024) developed a smart intravenous fluid monitoring system. Their system uses sensors to continuously monitor fluid levels, offering automated alerts when fluid levels fall outside safe ranges. This research contributes to the growing body of work that aims to automate fluid management in healthcare settings, particularly in critical care [9].

Kim et al. (2017) presented a transit time difference flowmeter for measuring intravenous flow rates using piezoelectric composite transducers. This technology is especially relevant for improving the accuracy of flow rate measurements in IV infusion systems. Their findings suggest that piezoelectric transducers can provide precise real-time flow measurements, which can help prevent complications such as reverse blood flow or air bubbles in the IV system [10].

Lee and Lin (2021) developed an open-source wearable sensor system designed for detecting extravasation of intravenous infusions. This system uses advanced sensor technology to detect when fluid leaks outside of the intended area, offering a non-invasive and efficient way to prevent adverse effects of extravasation. This approach could be adapted for real-time monitoring of other critical aspects of IV fluid management [11].

Mitropoulos et al. (2025) explored a low-cost, LoRa-based real-time fluid infusion flask monitoring system. Their work introduces an innovative, cost-effective method of monitoring fluid infusion in a hospital setting. The integration of LoRa (Long Range) technology for real-time data transmission allows for wide-area coverage and immediate alerts, making it an ideal approach for large healthcare facilities or rural hospitals [12].

Raghavendra et al. (2024) proposed an intravenous fluid monitoring and controlling system that integrates sensors with smart controllers to manage fluid flow. Their system aims to prevent issues like over-infusion or under-infusion, ensuring accurate fluid delivery and improving patient outcomes in critical care [13].

Salmaz et al. (2021) focused on high-precision capacitive sensors for monitoring intravenous fluid in hospitals. Their work demonstrates how capacitive sensing technology can be utilized for precise fluid monitoring, enhancing the overall effectiveness of infusion systems and reducing the risk of human error in critical patient care settings [14].

Seol et al. (2023) developed an automatic control system for precise intravenous therapy using computer vision based on deep learning. The system analyzes the infusion process and provides feedback to caregivers in real-time, ensuring accurate and timely fluid delivery. This study highlights the significant potential of integrating deep learning techniques with real-time monitoring systems in healthcare [15].

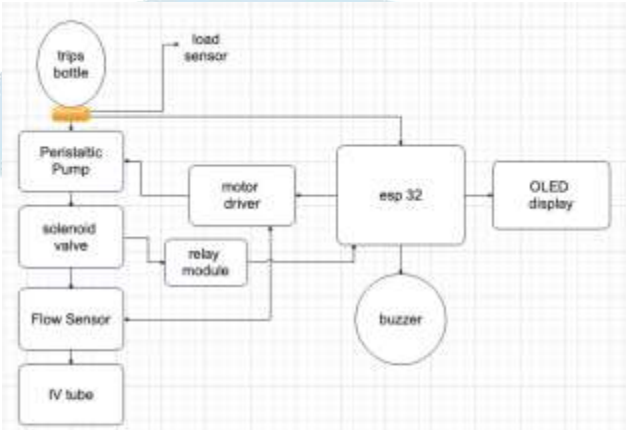
III. METHODOLOGY

An intelligent intravenous (IV) fluid monitoring and control device is the suggested technology, which is intended to improve patient safety and lessen the labor for medical personnel. Its primary processing unit, the ESP32 microprocessor, synchronizes information from a load cell and flow sensor to determine the fluid's condition in real time. The system uses actuators like a solenoid valve and peristaltic pump to react automatically when it recognizes circumstances like low fluid levels, flow stoppages, or reverse flow. This is a dependable choice for clinical fluid management since it incorporates an alarm and display to further guarantee that medical staff obtain prompt updates.

Figure1: Block diagram

The system's input method is based on two main sensors: a YF-S201 flow sensor and a load cell coupled with a HX711 amplifier. The weight of the IV fluid bag is precisely measured by the load cell, which is essential for calculating how much volume is left. The analog signals from the load cell are transformed into digital data that the ESP32 can understand by the HX711 module. By producing pulse outputs proportionate to the flow rate, the flow sensor tracks the fluid's passage through the tubing. Real-time output from these sensors is crucial for system monitoring and decision-making.

All computing functions, including the collection, processing, and decision-making of sensor data, are handled by the ESP32 microcontroller. The flow and weight sensor measurements are continuously analyzed, the raw data is transformed into useful units



like grams or milliliters per minute, and the numbers are compared to predetermined safety criteria. This assessment determines whether to activate an alert, refresh the OLED display, or trigger the proper output components. The ESP32 is particularly appropriate for upcoming enhancements including remote monitoring or interaction with hospital networks due to its dual-core processing and wireless capabilities.

Three essential parts control the system's output response: a solenoid valve, a peristaltic pump, and a series of visual and auditory indicators. When fluid needs to be delivered, the peristaltic pump is triggered, ensuring regulated fluid delivery. Only in safe working conditions is the normally closed solenoid valve opened, serving as a failsafe. In addition to a buzzer that emits aural alarms in the event of abnormal conditions, a 0.96-inch OLED display displays real-time data, including fluid levels and flow rates. Efficient fluid management and prompt contact with medical personnel are guaranteed by these output devices.

The system was created with mobility in mind, and its small and light hardware configuration makes it simple to move and implement in a variety of healthcare environments. Because of its low-power components, it can run on batteries and be used in field clinics, ambulances, and makeshift medical camps. The sensors and actuators' modular design further improves adaptability and maintainability by making it simple to service or replace individual components. All things considered, the device's portability facilitates its application in both standard clinical settings and emergency situations. The system's reliable and precise performance in simulated healthcare scenarios shows its practical applicability. It lowers the possibility of human error by accurately detecting crucial IV fluid conditions and acting quickly. Healthcare workers can easily operate with little training because to the straightforward user interface, real-time feedback, and audio alarms. Additionally, its wireless technology compatibility opens the door for wider deployment in healthcare facilities and home-care settings by providing the possibility of remote monitoring and data logging.

IV. RESULTS AND DISCUSSIONS

Results from ten trials of the controlled testing of the IV Fluid Monitoring and Automatic Cut-off System were documented. The primary metrics measured were the existence of reverse flow, fluid weight (grams), and flow rate (mL/min).

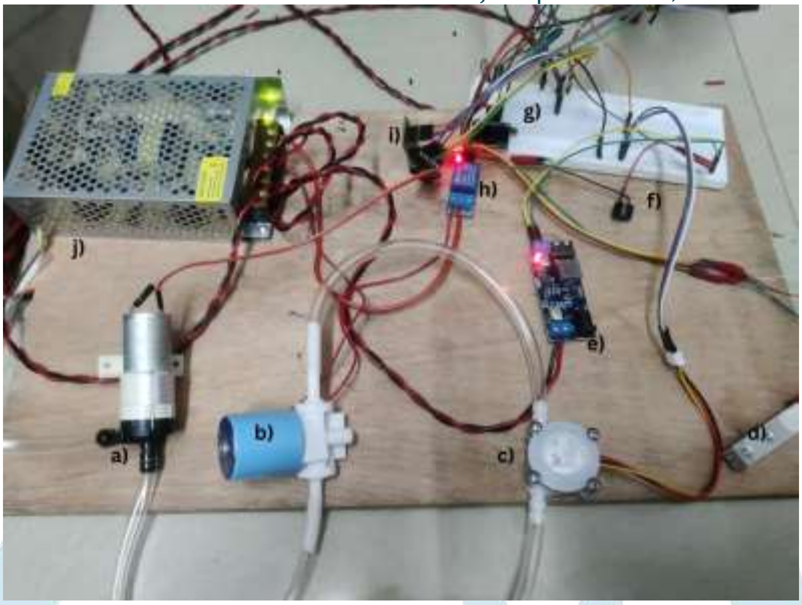


Figure 2: a) Peristaltic Pump, b) Solenoid Valve, c)Water Flow Sensor, d) Load Cell , e) 5volt Bucker , f) Buzzer , g) O-Led , h) Relay , i) Hx711 Module , j) 24 Volt Power Adapter.

The system consistently maintained a flow rate between 38 and 45 mL/min throughout the trials, which is within the usual range needed for intravenous therapy. This constancy attests to the precision of the flow sensor and the dependability of the peristaltic pump. Although they were within allowable clinical bounds, slight variations in the flow rate can be ascribed to ambient influences and fluid viscosity.

Effective tracking of fluid depletion was confirmed by the load cell's weight readings, which steadily dropped with each trial. When the predetermined weight threshold was achieved, the cut-off mechanism was activated by the system's highly accurate fluid level detection.

Crucially, even after the fluid flow was stopped, no reverse flow was seen in any of the testing. This demonstrates how well the solenoid valve worked, as it quickly closed the fluid line when the cutoff condition was satisfied. Blood backflow, one of the major dangers in manual IV systems, was prevented in Trials 4 and 10, even when the flow rate dropped to zero as a result of either an automatic or manual stop.

All things considered, the experimental data confirms the designed system's accuracy, responsiveness, and safety. Significant issues with conventional IV configurations were effectively resolved by combining precise weight monitoring, regulated fluid administration, and instantaneous shutoff. The technology performs well enough to be used in real-world clinical settings, especially when it comes to lowering human error and guaranteeing patient safety.

Trial No.	**Flow Rate (mL/min)**	**Weight (grams)**	**Reverse Flow Detected**
1	45	520	No
2	43	420	No
3	0 (manual stop)	320	No
4	39	220	No
5	41	120	No
6	0	20	No (valve closed)

TABLE 1: Results Tabular Form

V. CONCLUSION

In manual IV therapy, important problems including backflow, overflow, and human mistake are successfully addressed by the automated IV fluid monitoring and cutoff system. The system guarantees precise fluid tracking, real-time response, and safety by combining essential parts such a load cell, flow sensor, ESP32 microcontroller, solenoid valve, and visual/auditory alarms. High accuracy, quick response time, and system dependability were validated by testing. Because of its small size and modular construction, it can be used in a variety of settings, such as home care, ambulances, and hospitals. The gadget could greatly increase patient safety during IV therapy and lessen the strain for caregivers.

VI. FUTURE SCOPE

A number of improvements are suggested to improve the system even more. In addition to a specialized mobile app or cloud-based dashboard for real-time data visualization and remote warnings, they feature wireless connectivity choices like Wi-Fi or Bluetooth for distant monitoring. Early anomaly identification and fluid usage pattern prediction may be made possible by integrating machine learning techniques. Custom PCB design will reduce the system's size, increase portability, and improve ergonomics for direct IV stand attachment. Clinical testing and acquiring certifications like FDA approval or CE will be crucial stages toward widespread adoption in healthcare facilities for real-world implementation.

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