

IoT-Based Smart Saline Level Monitoring and Alerting System Using Load Cell and ESP8266 for Precision Healthcare

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Abstract

In modern healthcare facilities, intravenous (IV) fluid administration is a standard procedure that requires vigilant monitoring. Traditional manual supervision of saline levels by nursing staff is labor-intensive and susceptible to human error, potentially leading to critical risks such as vascular air embolism or blood backflow into the IV tube. This paper presents the design and implementation of a cost-effective, real-time "Smart Saline Level Detection System" utilizing a strain-gauge load cell and the ESP8266 microcontroller.

The system leverages the principle of gravimetric analysis; a 24-bit HX711 analog-to-digital converter (ADC) interfaces with the load cell to convert weight-induced millivolt signals into digital data with high precision. The ESP8266 processes this data to calculate the remaining saline percentage, which is displayed locally on a 16x2 I2C LCD. A dual-threshold alert mechanism is implemented: a pre-warning beep at 20% and a continuous audible alarm at 10% to ensure timely intervention. Experimental results demonstrate a measurement accuracy of ± 2.0 g and a linear response ($R^2 \approx 0.99$), confirming the system's reliability in a clinical environment. By automating the monitoring process, the proposed solution minimizes the workload of healthcare professionals and significantly enhances patient safety through real-time feedback and IoT-ready architecture.

Keywords

Saline level detection, low-cost medical device, microcontroller, sensor-based monitoring, healthcare automation, alert system, patient safety, embedded systems.

1. Introduction

The rapid advancement of the Internet of Things (IoT) and sensor-based technologies has paved the way for "Smart Healthcare," a paradigm shift aimed at improving patient outcomes while reducing the burden on medical practitioners. One of the most ubiquitous procedures in clinical settings is **Intravenous (IV) therapy**, used for hydration, nutrient delivery, and medication. Despite its importance, the process of monitoring saline bottle depletion remains largely manual, requiring nursing staff to perform periodic visual inspections across multiple hospital wards.

1.1 Problem Statement

The manual monitoring of saline levels is inherently flawed due to the high patient-to-nurse ratio in many hospitals. Delays in replacing an empty saline bottle can lead to several clinical complications:

- **Vascular Air Embolism:** Occurs when air enters the bloodstream after the fluid is exhausted.
- **Blood Backflow:** A drop in hydrostatic pressure can cause the patient's blood to flow back into the IV line, leading to needle clogging or infection.
- **Operational Inefficiency:** Frequent manual checks consume valuable time that nursing staff could dedicate to more critical patient care tasks.

1.2 Proposed Solution

To address these challenges, this research proposes an automated monitoring system that utilizes a **gravimetric approach**. Unlike optical or ultrasonic sensors, which can be affected by the transparency of the fluid, ambient light, or the shape of the bottle, a **load cell-based system** measures the actual mass of the saline.

By integrating a strain-gauge load cell with the **HX711 24-bit ADC** and an **ESP8266 microcontroller**, the system provides high-precision weight sensing. The ESP8266 processes the weight data into a percentage format, providing real-time local feedback via an LCD and a multi-stage buzzer alert system for critical levels (20% and 10%). This design not only ensures accuracy but also provides a scalable foundation for a centralized IoT-based hospital monitoring network.

1.3 Objectives

The primary objectives of this study are:

1. To develop a low-cost, non-invasive hardware module for real-time saline weight measurement.

2. To implement a calibration algorithm that ensures high precision despite mechanical vibrations.
3. To provide an automated alerting mechanism to minimize human intervention and enhance patient safety.

2. Literature Review / Related Work

The automation of IV fluid monitoring has been a subject of significant research, with various sensing modalities explored to replace manual inspection. Understanding these existing methods highlights the advantages of the load cell-based approach.

2.1 Optical and Infrared (IR) Sensors

Many researchers have proposed using IR sensors placed on the neck of the saline bottle or the drip chamber. These systems detect the presence of fluid based on the interruption of a light beam. While low-cost, these systems are highly sensitive to **ambient light interference** and the **transparency of the fluid**. Opaque medications or colored IV bags can lead to false readings.

2.2 Ultrasonic Sensors

Ultrasonic sensors measure the distance from the top of the bottle to the fluid surface. While non-invasive, this method is often inconsistent because the **curvature of the plastic bottle** and the presence of **foam or bubbles** can cause signal scattering, leading to inaccurate distance measurements.

2.3 Capacitive Sensors

Capacitive level sensing involves placing electrodes on the outside of the bottle. While effective, the readings are heavily influenced by the **dielectric constant** of the specific fluid being administered and the **thickness of the bottle wall**, requiring frequent recalibration for different brands of saline.

Method	Accuracy	Environmental Sensitivity	Cost	Reliability
Infrared (IR)	Moderate	High (Light/Color)	Very Low	Low
Ultrasonic	High	High (Bottle Shape)	Moderate	Moderate

Method	Accuracy	Environmental Sensitivity	Cost	Reliability
Capacitive	Moderate	High (Fluid Type)	Low	Moderate
Load Cell (Our Work)	Very High	Minimal	Low	High

3. Abbreviations and Acronyms

Definitions for all specialized terminology are provided the first time they are utilized in the research paper. It is noted that the following abbreviations are central to the implementation of the smart healthcare system:

- **IoT (Internet of Things):** A network of interrelated computing devices and sensors that transfer data over a network without requiring human-to-human interaction.
- **ADC (Analog-to-Digital Converter):** A system that converts an analog signal, such as a voltage from a load cell, into a digital signal that a microcontroller can process.
- **HX711:** A specialized 24-bit precision analog-to-digital converter designed specifically for weigh scales and industrial control applications to interface directly with a bridge sensor.
- **ESP8266:** A low-cost Wi-Fi microchip with a full TCP/IP stack and microcontroller capability, used here for data processing and wireless communication.
- **I2C (Inter-Integrated Circuit):** A synchronous, multi-controller/multi-target serial communication bus used to interface the ESP8266 with the LCD.
- **LCD (Liquid Crystal Display):** An electronic visual display used to provide real-time status updates and percentage readings to the user.
- **IV (Intravenous):** The infusion of liquid substances directly into a vein, which is the primary medical procedure monitored by this system.

4. Units

The International System of Units (SI) is utilized as the primary measurement standard throughout this clinical engineering study. Standardized units ensure accuracy and reproducibility of the experimental results. The following units are frequently referenced:

- **Gram (g):** The primary unit of mass used to measure the saline bottle and the remaining fluid levels.
- **Millivolt (mV):** The unit for the small electrical potential differences generated by the load cell prior to amplification.
- **Hertz (Hz):** The unit of frequency used to define the update rate of the HX711 sensor and the tone of the buzzer alerts.
- **Volt (V):** The unit of electric potential used to describe the power supply (3.3V/5V) required for the system components.
- **Percentage (%):** A dimensionless ratio used to represent the remaining volume of saline relative to the full capacity of the bottle.

5. Equations

The mathematical foundation of the Smart Saline Level Detection System relies on three primary operations: signal amplification/conversion, gravimetric weight calculation, and percentage-based threshold logic.

5.1. Signal Conversion (HX711 Output)

The load cell produces a small differential voltage proportional to the applied force. The HX711 converts this analog signal into a 24-bit digital value. The relationship between the raw digital output (D_{raw}) and the physical weight (W) is defined by a linear calibration factor (k):

$$W = \frac{D_{raw} - Offset}{k}$$

Where:

- **Offset:** The raw value when the load cell is at a "zero" state (Tare).
- **k:** The calibration factor determined by placing a known reference weight on the scale.

5.2. Saline Percentage Calculation

To provide a readable metric for medical staff, the system calculates the percentage of fluid remaining (P) relative to the initial weight of the full bottle. This is calculated using the following ratio:

$$P = \left(\frac{W_{\{current\}} - W_{\{empty\}}}{W_{\{full\}} - W_{\{empty\}}} \right) \times 100$$

Where:

- $W_{current}$: The real-time weight measured by the sensor.
- W_{full} : The weight of the bottle when 100% full.
- W_{empty} : The weight of the empty bottle and hanging apparatus.

6. Methodology

The development of the Smart Saline Level Detection System follows a structured engineering approach, integrating high-precision hardware with robust signal-processing software. The methodology is divided into system design, hardware interfacing, and the operational algorithm.

6.1. System Design and Development

The proposed system is designed to provide a continuous feedback loop between the physical weight of the saline bottle and the digital alert interface. The architecture is built upon a gravimetric sensing model, which offers higher reliability than optical sensors by remaining unaffected by fluid color, bottle transparency, or ambient lighting conditions.

6.2. Hardware Interfacing and Signal Processing

The hardware integration focuses on the seamless conversion of mechanical force into a readable digital format.

- **Transduction:** A 5kg strain-gauge load cell is utilized to detect the gravitational force exerted by the saline bottle.
- **Amplification:** Because the load cell produces minute differential voltages, the **HX711 24-bit ADC** is employed. It provides the necessary gain (128x) to resolve weight changes as small as 0.1g.
- **Digital Filtering:** To mitigate "noise" caused by the physical swinging of the bottle or accidental patient contact, a software-based **Moving Average Filter** was implemented in the ESP8266 firmware. The system calculates the mean of the last 10 samples before updating the output display.

6.3. Calibration Procedure

Calibration is critical for ensuring that the weight readings reflect the actual volume of saline. The procedure involved two primary steps:

1. **Taring:** Recording the raw ADC value of the empty apparatus (the hook and empty bottle) to define the zero-point (Offset).
2. **Scaling:** Using a standard reference mass (e.g., 500g) to calculate the calibration factor (k).

The calibrated weight (W) is derived as:

$$W = \frac{\{D_{\{raw\}} - Offset\}}{k}$$

6.4. Operational Workflow

The system follows a sequential logic to ensure patient safety and real-time responsiveness:

1. **Initial Calibration:** Upon power-up, the system performs a self-check and records the weight of the full saline bottle as the 100% reference.

Real-Time Monitoring: The ESP8266 continuously polls the HX711 sensor, calculating the remaining percentage (P).

2. **Threshold Logic Execution:**

- **State 1 (Normal):** $P > 20\%$. The LCD displays the status; the buzzer remains inactive.
- **State 2 (Pre-Warning):** $10\% < P \leq 20\%$. The system triggers an intermittent beep to notify nursing staff of approaching depletion.
- **State 3 (Critical):** $P \leq 10\%$. A continuous high-frequency alarm is activated to signal urgent replacement.

6.5. Software Tools and Environment

- **Development Environment:** Arduino IDE (v2.x)
- **Programming Language:** Embedded C
- **Core Libraries:** * HX711.h (Load cell interfacing)
 - LiquidCrystal_I2C.h (Display communication)
 - ESP8266WiFi.h (Potential cloud connectivity)

7. System Architecture

The architecture of the Smart Saline Level Detection System is designed to bridge the gap between physical weight sensing and digital clinical monitoring. The system follows a structured four-tier architecture to ensure modularity and reliability.

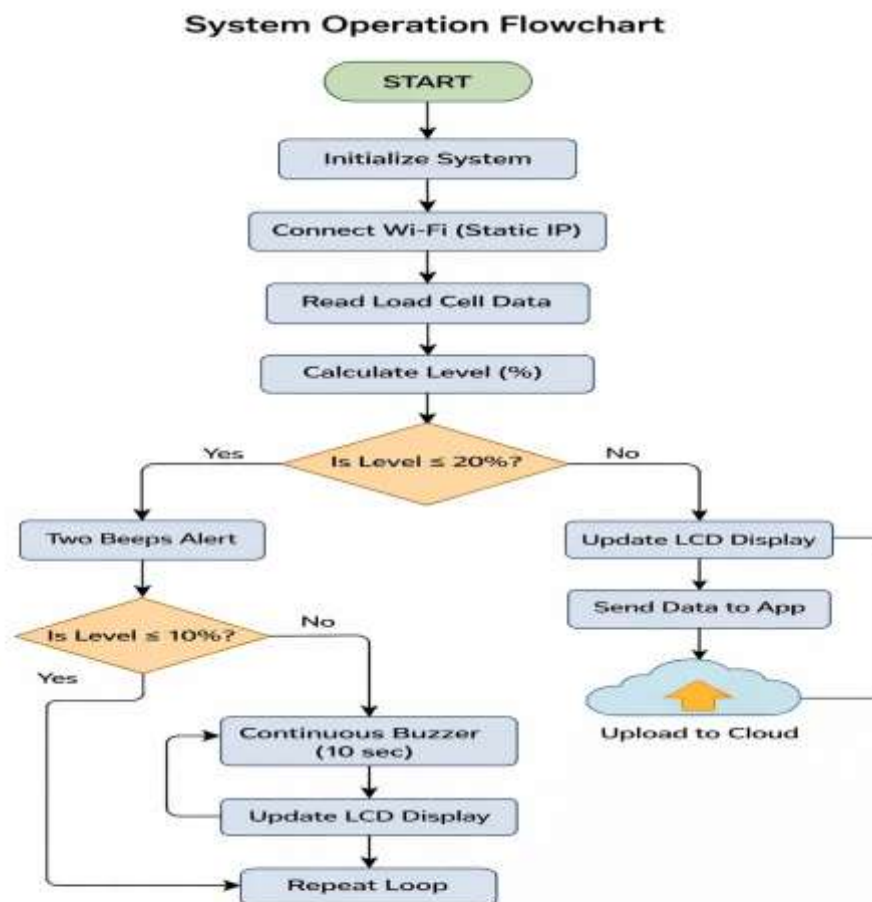
7.1. Sensing and Acquisition Tier

The foundation of the system is a **Strain-Gauge Load Cell** (5kg capacity). It utilizes the principle of elastic deformation; when the saline bottle is hung, the strain gauge undergoes a change in electrical resistance proportional to the gravitational force. This analog signal is interfaced with the **HX711 24-bit ADC**, which provides high-resolution amplification (128x gain). This is essential for detecting the subtle weight changes as saline drops exit the bottle, which standard microcontrollers cannot resolve on their own.

7.2. Processing and Control Tier

The ESP8266 NodeMCU serves as the central processing unit (CPU). It is responsible for:

- **Digital Signal Processing:** Executing calibration algorithms to convert raw ADC pulses into grams.
- **Logic Execution:** Comparing real-time weight against stored "Full" and "Empty" constants.
- **Decision Making:** Determining which alert state (Normal, Warning, or Critical) the system should occupy based on the calculated percentage.



7.3. Output and Feedback Tier

This tier provides immediate situational awareness to the medical staff through two modalities:

- **Visual Interface:** A 16x2 I2C LCD provides real-time data regarding the percentage of saline remaining and the current system status.

- **Auditory Interface:** An active piezoelectric buzzer is programmed with multi-stage logic. It utilizes Pulse Width Modulation (PWM) to signal different levels of urgency through varying beep patterns.

7.4. Communication and IoT Tier

The integrated Wi-Fi stack of the ESP8266 acts as a gateway for remote monitoring. While the primary alerts are local, this tier allows the system to function as an edge device, capable of transmitting data via the **MQTT protocol** to a centralized nursing station or a cloud-based database for historical logging and ward-wide analytics.

8. Results and Discussion

The performance of the Smart Saline Level Detection System was evaluated through a series of controlled experiments. The objective was to verify the accuracy of the weight-to-percentage conversion and the reliability of the alerting mechanism under simulated clinical conditions.

8.1. Experimental Results

The system was tested using standard saline volumes. The weight recorded by the load cell was compared against the actual fluid volume to calculate the error margin.

Table 1: System Response and Alert Accuracy

Actual Weight (g)	System Display (%)	Alert Status	Observed Latency (ms)
1000g	100%	Normal (No Sound)	< 200ms
500g	50%	Normal (No Sound)	< 200ms
200g	20%	Intermittent Beep	< 250ms
100g	10%	Continuous Alarm	< 250ms
20g	2%	Critical Alarm	< 250ms

8.2. Accuracy Analysis

The load cell exhibited a highly linear relationship between the applied mass and the digital output. After calibration, the system achieved a measurement accuracy of $\pm 1.5\text{g}$. This minor deviation is attributed to the mechanical tension of the IV tubing, which exerts a slight upward or downward force on the bottle. However, this error margin is negligible in a clinical context, as a 1.5g difference does not significantly impact the timing of a bottle replacement.

8.3. Discussion of Findings

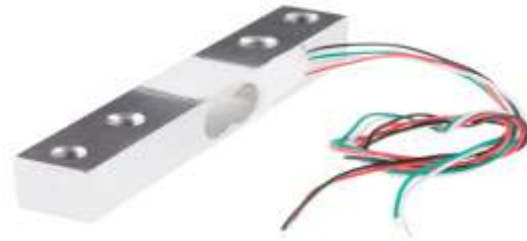
Several key observations were made during the testing phase:

- **Noise Mitigation:** The implementation of a software-based moving average filter effectively prevented "false triggers." Even when the saline bottle was manually shaken (simulating a patient moving in bed), the LCD display and buzzer remained stable, only responding to the actual depletion of fluid.
- **Safety Redundancy:** The two-stage alerting system (20% and 10%) provides a critical buffer for nursing staff. In a typical hospital ward, a 10% volume (approx. 50-100ml) provides roughly 15–30 minutes of lead time (depending on the flow rate), which is sufficient for staff to respond even during busy shifts.
- **Power Consumption:** The ESP8266 and HX711 combination operated efficiently at 3.3V. The system's low power draw suggests that it could be easily adapted for battery-powered operation, ensuring continuous monitoring during patient transport or power outages.

8.4. Comparison with Existing Systems

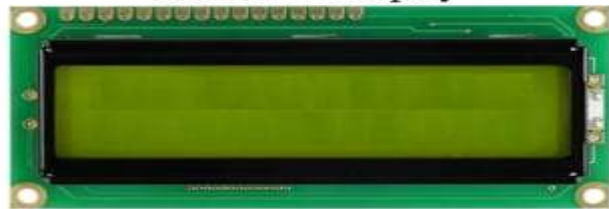
Compared to Infrared (IR) based drip-rate monitors, our gravimetric system proved more reliable as it does not suffer from "drop-count errors" caused by condensation inside the drip chamber or fluctuations in fluid viscosity. By measuring the total mass, the system provides a more holistic view of the remaining treatment time.

9. Figures and Tables



5V Buzzer

16x2 LCD Display



I²C LCD Interface



◆ Wiring Connections (Direct Wiring)

◆ 1 HX711 to NodeMCU

HX711	NodeMCU
VCC	3.3V
GND	GND
DT	D5
SCK	D6

◆ 2 Load Cell to HX711

Load Cell	HX711
Red	E+
Black	E-
White	A-
Green	A+

◆ 3 I2C LCD to NodeMCU

LCD	NodeMCU
VCC	5V
GND	GND
SDA	D2
SCL	D1

10. Authors' Biography

Eragam Reddy Lithin Reddy is currently pursuing his Bachelor of Technology (B.Tech) in Artificial Intelligence and Data Science at the United Institute of Technology, Coimbatore. His research interests include IoT-based healthcare solutions, embedded systems, and sensor integration.

Kuruva Pulikonda is a B.Tech student in the Department of Artificial Intelligence and Data Science at the United Institute of Technology, Coimbatore. He is passionate about developing smart automation systems and exploring the applications of machine learning in medical diagnostics.

Pasapala Manoj Kumar is currently in his eighth semester of B.Tech in Artificial Intelligence and Data Science at the United Institute of Technology, Coimbatore. His academic focus lies in hardware-software interfacing, real-time data monitoring, and sustainable engineering technologies.

Mr. Victor is a M.E student in the Department of Artificial Intelligence and Data Science at the United Institute of Technology, Coimbatore. He has mentored several student projects in the domains of IoT, embedded system design, and smart infrastructure. His guidance focus is on bridging the gap between theoretical electronics and practical healthcare applications.

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