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Design and Implementation of a Real-time Smart Saline Monitoring, Detection, and GSM-based Emergency Notification System for Modern Healthcare Environments

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ABSTRACT

In modern healthcare systems, continuous patient monitoring plays a vital role in ensuring safety and timely medical intervention. One of the common challenges in hospitals is the manual monitoring of intravenous (IV) saline bottles, which often leads to human error, delayed response, and potential health risks such as blood backflow and air embolism. To address these issues, this paper presents a Smart Saline Monitoring System using a load cell and GSM module for real-time and automated saline level monitoring. The proposed system employs a load cell sensor to accurately measure the weight of the saline bottle, which directly corresponds to the fluid level. The sensed data is processed using a microcontroller, where it is continuously compared with predefined threshold values. When the saline level falls below the critical limit, the system automatically triggers an alert mechanism and sends an SMS notification to the medical staff through the GSM module, ensuring immediate attention without the need for constant supervision. The system is designed to be cost-effective, reliable, and easy to integrate into existing hospital infrastructure. Experimental evaluation demonstrates that the system provides accurate measurements and quick response times under various conditions. By reducing manual workload and enhancing monitoring efficiency, the proposed solution significantly improves patient safety and operational efficiency in healthcare environments.

This paper presents a Smart Saline Monitoring System based on a load cell sensor and GSM communication to achieve accurate and real-time monitoring of intravenous (IV) fluid levels. The system measures the weight of the saline bottle using a load cell interfaced with an HX711 precision amplifier. The system operates with a response time of less than 5 seconds and achieves measurement accuracy within ±2% after calibration. Experimental validation confirms reliable performance under varying load conditions. The proposed system significantly reduces manual intervention, enhances patient safety, and provides a low-cost, scalable solution suitable for real-time healthcare monitoring applications.

Keywords: Smart Saline Monitoring System; Intravenous Fluid Monitoring; Load Cell Sensor; GSM Communication; Real-time Monitoring; Patient Safety; Healthcare Automation; Microcontroller-based System; Medical Alert System; Internet of Medical Things.

1. Introduction

In recent years, the healthcare sector has witnessed rapid advancements in medical technologies aimed at improving patient care, safety, and operational efficiency. Continuous monitoring of patients is a fundamental requirement in hospitals, especially in critical care units where even a minor delay in response can lead to serious consequences. One of the most routine yet crucial tasks in medical practice is the administration and monitoring of intravenous (IV) fluids, commonly delivered through saline bottles. These fluids play a vital role in maintaining hydration, delivering medications, and supporting various physiological functions in patients.

Despite its importance, the monitoring of saline bottles is still largely performed manually in many hospitals. Nurses and healthcare staff are required to periodically check the fluid level and replace the bottle when it becomes empty. However, in real-time hospital environments where a single nurse may be responsible for multiple patients, continuous manual monitoring becomes impractical and error-prone. This often leads to delayed replacement of saline bottles, increasing the risk of complications such as blood backflow into the IV line and air embolism, which can be life-threatening if not addressed immediately.

The limitations of manual monitoring highlight the need for an automated and reliable system that can continuously track the saline level and notify medical personnel without delay. Automation in healthcare not only reduces human workload but also significantly improves accuracy and response time. With the emergence of embedded systems, sensor technologies, and wireless communication, intelligent monitoring solutions can now be developed to address such challenges effectively.

In this context, the proposed Smart Saline Monitoring System introduces an efficient method for real-time monitoring of IV fluid levels using a load cell sensor and GSM communication. The load cell is used to measure the weight of the saline bottle, which provides a direct and accurate indication of the remaining fluid. Unlike conventional level detection methods such as float sensors or infrared sensors, the load cell offers higher precision and reliability, making it suitable for medical applications.

The sensed data from the load cell is processed using a microcontroller, which continuously analyzes the weight and compares it with predefined threshold values. When the saline level reaches a critical point, the system automatically generates an alert. To ensure immediate communication, a GSM module is integrated into the system, which sends an SMS notification to the concerned medical staff. This wireless communication eliminates the need for physical presence and enables remote monitoring, thereby improving efficiency in hospital operations.

Another significant advantage of the proposed system is its independence from internet connectivity. Unlike IoT-based solutions that rely on network availability, the GSM-based approach ensures reliable communication even in areas with limited or no internet access. This makes the system more practical and adaptable for a wide range of healthcare environments, including rural and resource-limited settings.

Furthermore, the system is designed to be cost-effective, easy to install, and scalable. It can be deployed across multiple hospital beds without requiring complex infrastructure changes. The simplicity of the design and the use of widely available components make it suitable for large-scale implementation. In addition, the system reduces the workload of nurses, allowing them to focus on more critical patient care tasks.

This paper presents the design, implementation, and evaluation of the Smart Saline Monitoring System. The performance of the system is analyzed in terms of accuracy, response time, and reliability. The results demonstrate that the proposed system effectively addresses the challenges associated with manual monitoring and provides a practical solution for real-time healthcare applications.

Overall, the integration of sensing technology with wireless communication in the proposed system represents a significant step toward smart healthcare solutions. By ensuring timely alerts and continuous monitoring, the system enhances patient safety, minimizes risks, and contributes to the advancement of automated medical systems.

░ 2. Related Work

The development of automated saline monitoring systems has gained significant attention in recent years due to the increasing demand for improved patient safety and reduced workload on healthcare staff. Various techniques and technologies have been explored by researchers to overcome the limitations of manual monitoring systems.

Early approaches to saline monitoring primarily relied on simple level detection techniques using float sensors and infrared (IR) sensors. In these systems, the presence or absence of fluid was detected based on the position of a float or the interruption of an IR beam. Although these methods were simple and cost-effective, they lacked precision and were unable to provide continuous monitoring of fluid levels. Additionally, such systems were prone to errors due to sensor misalignment and environmental factors.

Subsequently, microcontroller-based systems were introduced using platforms such as Arduino and PIC controllers. These systems incorporated sensors along with buzzer alarms to notify medical staff when the saline level dropped below a certain limit. While these designs improved automation to some extent, they were limited by their local alert mechanisms, requiring the presence of healthcare personnel near the patient. This reduced their effectiveness in busy hospital environments where continuous supervision is difficult.

With the advancement of wireless communication technologies, GSM-based monitoring systems were developed to enable remote alerting. In these systems, a GSM module is interfaced with a microcontroller to send SMS notifications when critical conditions are detected. GSM-based systems offer the advantage of wide network coverage and independence from internet connectivity. However, many of these implementations used basic level detection sensors, which limited the accuracy and reliability of the monitoring process.

More recent research has focused on Internet of Things (IoT)-based saline monitoring systems. These systems utilize sensors connected to cloud platforms, allowing real-time data monitoring through mobile applications or web interfaces. IoT-based solutions provide enhanced features such as data logging, visualization, and remote access. However, they are highly dependent on stable internet connectivity and may involve higher implementation costs and complexity. In addition, concerns related to data security and network reliability can affect their practical deployment in healthcare environments.

Some studies have also explored the use of weight-based monitoring techniques using load cells. These systems measure the weight of the saline bottle to determine the remaining fluid level more accurately. Compared to conventional sensors, load cells provide higher precision and are less affected by external environmental conditions. However, many existing implementations lack an efficient communication mechanism for real-time alerting or do not integrate advanced notification systems.

In comparison with the existing methods, the proposed system combines the advantages of weight-based measurement and GSM communication to provide a more reliable and efficient solution. The use of a load cell ensures accurate and continuous monitoring of the saline level, while the GSM module enables instant alert notifications without relying on internet connectivity. This integration overcomes the limitations of earlier systems, such as low accuracy, restricted communication range, and dependency on network infrastructure.

Therefore, the proposed Smart Saline Monitoring System offers a balanced approach by achieving high accuracy, real-time monitoring, and reliable communication, making it more suitable for practical deployment in hospitals and healthcare facilities.

3. Proposed System

The proposed Smart Saline Monitoring System is designed to provide continuous, accurate, and real-time monitoring of intravenous (IV) fluid levels using a load cell sensor and GSM communication. The system aims to eliminate the drawbacks of manual monitoring by automating the detection and alert process, thereby enhancing patient safety and reducing the workload on healthcare staff. The overall system consists of a load cell sensor, HX711 amplifier module, microcontroller unit (Arduino), GSM module, and a display unit.

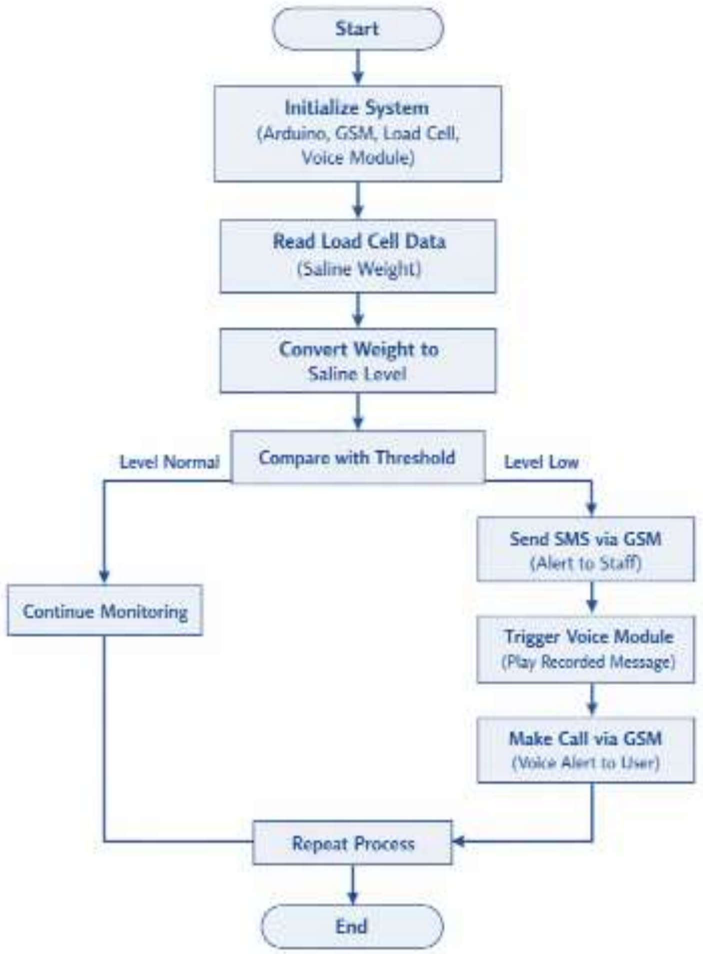

Figure 1. Flowchart of the Proposed Model

The load cell is used to measure the weight of the saline bottle, which directly corresponds to the amount of fluid present. The analog signal generated by the load cell is very small and requires amplification; therefore, the HX711 module is used to amplify and convert the signal into digital form for accurate processing.

4. Methodologies and Technologies

4.1. Methodology

The proposed Smart Saline Monitoring System follows a systematic approach to ensure accurate measurement, real-time monitoring, and timely alert generation. The methodology is divided into the following stages:

Step 1: System Initialization

In the initial stage, all hardware components such as the load cell, HX711 amplifier module, microcontroller (Arduino), GSM module, and display unit are properly connected and powered. The GSM module is initialized with a valid SIM card having an active network. The microcontroller is programmed and configured to establish communication with all peripherals.

Step 2: Load Cell Calibration

The load cell sensor is calibrated to ensure accurate weight measurement. Known weights are used to determine the calibration factor, which establishes the relationship between the sensor output and actual weight. This step is essential to achieve precise saline level estimation.

Step 3: Data Acquisition

The load cell continuously senses the weight of the saline bottle and generates a small analog signal proportional to the applied load. This signal is transmitted to the HX711 module, which amplifies and converts it into a digital signal for further processing.

Step 4: Signal Processing

The digital data from the HX711 module is read by the microcontroller. The system processes this data to calculate the actual weight of the saline bottle. Using pre-calibrated values, the remaining fluid level is determined accurately.

Step 5: Threshold Evaluation

The calculated weight is continuously compared with predefined threshold values stored in the microcontroller. These thresholds represent critical saline levels (e.g., 10–15% of total volume). If the measured weight falls below the threshold, the system identifies it as a critical condition.

Step 6: Alert Generation

When a critical condition is detected, the microcontroller activates the alert mechanism. This triggers the GSM module to prepare for message transmission. The system ensures that the alert is generated only once per critical event to avoid repeated notifications.

Step 7: GSM Communication

The GSM module communicates with the microcontroller using UART protocol. AT commands are used to send SMS alerts to predefined mobile numbers. The alert message typically includes information such as “Saline Level Low – Replace Immediately,” ensuring clear communication to medical staff.

Step 8: Display and Indication

A display unit (LCD/LED) is used to show real-time information such as current saline level, system status, and alert messages. This provides a visual indication for nearby healthcare personnel and enhances system usability.

Step 9: Continuous Monitoring

The system operates in a continuous loop, repeatedly monitoring the saline level at regular intervals. This ensures real-time tracking and immediate response whenever the saline level reaches a critical condition.

Step 10: Testing and Validation

Finally, the system is tested under various conditions to evaluate its performance. Different saline levels are simulated to verify the accuracy of measurement and the reliability of alert generation. The results confirm that the system operates efficiently with minimal delay and high accuracy.

4.2. Technology

The proposed Smart Saline Monitoring System integrates multiple hardware and software technologies to achieve accurate sensing, data processing, and real-time communication. The key technologies used in the system are described below:

4.2.1. Load Cell Sensor

The load cell is the primary sensing element used to measure the weight of the saline bottle. It operates based on the principle of strain gauges, where mechanical deformation produces a proportional electrical signal. This allows precise measurement of the saline level, as the weight directly corresponds to the volume of fluid present.

4.2.2. HX711 Amplifier Module

The HX711 is a high-precision analog-to-digital converter (ADC) specifically designed for load cell applications. Since the output signal from the load cell is very small, the HX711 amplifies this signal and converts it into digital form. It ensures high accuracy and noise reduction in weight measurement.

4.2.3. Microcontroller (Arduino)

The microcontroller acts as the central processing unit of the system. It receives digital data from the HX711 module, processes the information, and determines the saline level. It also controls the GSM module and display unit based on programmed logic. The system is typically programmed using Embedded C/C++.

4.2.4. GSM Technology

Global System for Mobile Communication (GSM) is used for wireless data transmission. It enables the system to send SMS alerts to medical staff when the saline level reaches a critical condition. GSM technology is widely used due to its large coverage area and reliability without requiring internet connectivity.

4.2.5. GSM Module (SIM800/SIM900)

The GSM module serves as the communication interface between the system and the mobile network. It contains a SIM card slot and operates using AT commands. The module sends alert messages to predefined phone numbers when triggered by the microcontroller.

4.2.6. Serial Communication (UART)

UART (Universal Asynchronous Receiver Transmitter) protocol is used for communication between the microcontroller and the GSM module. It enables the exchange of data through TX (Transmit) and RX (Receive) pins, ensuring reliable and efficient communication.

4.2.7. Embedded Programming (C/C++)

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The system logic is implemented using embedded programming in C/C++. The program controls sensor data acquisition, processing, threshold comparison, and alert generation. Efficient coding ensures fast response and reliable system performance.

4.2.8. Display Unit (LCD/LED Display)

A display unit is used to show real-time information such as saline level, system status, and alert messages. It provides a user-friendly interface for healthcare personnel to monitor the system locally.

4.2.9. Power Supply

A regulated power supply is used to provide stable voltage to all components of the system. Proper power management ensures reliable operation and prevents damage to sensitive electronic components.

5. Result and Discussion

The Smart Saline Monitoring System was experimentally evaluated to analyze its accuracy, response time, reliability, and overall effectiveness in real-time healthcare applications. The system was tested using different saline levels by varying the weight applied to the load cell representing full, half, and near-empty conditions.

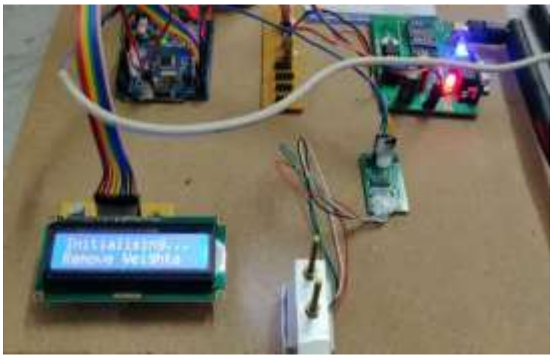

Figure 2. Screenshot 1

During calibration, the parameters WfullW_{full}Wfull, WemptyW_{empty}Wempty, and threshold weight WthW_{th}Wth were carefully determined. The system successfully mapped the weight values to corresponding saline levels using a linear relationship between load and sensor output. The load cell exhibited stable performance, and the HX711 module ensured high-resolution digital conversion, enabling precise measurement of small weight variations.

The system demonstrated consistent performance in detecting gradual decreases in saline level. As the fluid level approached the critical threshold (approximately 10–15% of total volume), the microcontroller accurately identified the condition and triggered the alert mechanism. The GSM module successfully transmitted SMS notifications using AT commands, with an average response time of 3–5 seconds. This quick response ensures timely intervention by medical staff.

To evaluate accuracy, multiple trials were conducted, and the measured values were compared with actual weights. The system achieved an accuracy of approximately ±2%, which is sufficient for practical medical applications. The error margin was primarily due to environmental factors such as vibration and minor calibration variations.

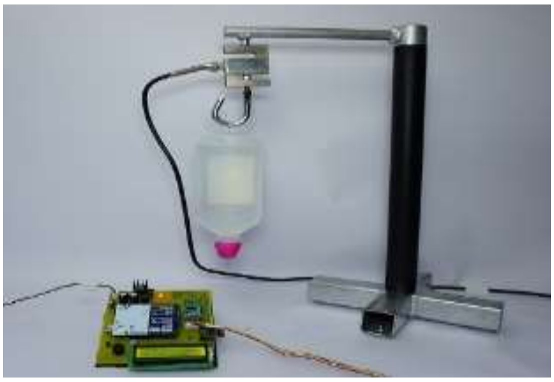

Figure 3. Screenshot 2

The system was also tested for continuous operation over extended periods. It maintained stable performance without signal drift or data loss, indicating high reliability. The display unit provided real-time feedback, displaying the current saline level and system status, which enhances usability for nearby healthcare personnel.

A comparative analysis with existing systems highlights the advantages of the proposed approach. Unlike float-based or IR sensor-based systems, the load cell provides continuous and precise measurement rather than binary level detection. Compared to IoT-based systems, the GSM-based communication ensures independence from internet connectivity, making it more reliable in areas with limited network infrastructure.

However, certain limitations were observed during testing. The GSM module performance depends on network availability, and delays may occur in regions with weak signal strength. Additionally, external disturbances such as sudden movement of the saline stand may slightly affect measurement accuracy. These issues can be minimized through proper mounting and signal filtering techniques.

Further testing included repeated alert scenarios and multiple threshold crossings, where the system consistently performed without failure. The alert mechanism was designed to avoid redundant notifications, ensuring efficient communication without message flooding.

Overall, the experimental results confirm that the proposed Smart Saline Monitoring System is efficient, accurate, and reliable. It significantly reduces manual monitoring effort, improves response time, and enhances patient safety. The integration of load cell sensing with GSM communication provides a practical and scalable solution for modern healthcare environments.

6. Conclusion and Future Enhancement

6.1. Conclusion

The proposed Smart Saline Monitoring System presents a robust and intelligent approach to automating the monitoring of intravenous (IV) fluid levels in healthcare environments. The system effectively replaces conventional manual supervision with a sensor-based, real-time monitoring mechanism that significantly improves reliability and response time. By employing a load cell sensor, the system achieves precise weight-based measurement, which provides a continuous and accurate estimation of the remaining saline volume compared to traditional discrete-level detection methods.

The integration of the HX711 high-resolution analog-to-digital converter ensures minimal signal noise and high measurement sensitivity, enabling the detection of even small variations in fluid level. The microcontroller-based processing unit efficiently performs real-time data acquisition, filtering, and threshold comparison, thereby ensuring prompt identification of critical conditions. The GSM communication module enhances the system by providing instant alert notifications through SMS, ensuring that medical personnel are informed without delay, regardless of their physical location.

From an operational perspective, the system demonstrates high stability and reliability under continuous monitoring conditions. The experimental analysis confirms that the system achieves an accuracy of approximately ±2% and maintains a rapid response time within a few seconds. These characteristics make the system highly suitable for deployment in real-world hospital scenarios where precision and timeliness are critical.

Moreover, the proposed system is designed with simplicity, cost-effectiveness, and scalability in mind. It does not rely on internet connectivity, which increases its applicability in remote or resource-constrained environments. By minimizing human intervention and reducing the chances of negligence, the system plays a significant role in enhancing patient safety and improving the overall efficiency of healthcare services. Thus, the proposed solution serves as a practical step toward the realization of smart and automated medical monitoring systems.

6.2. Future Enhancement

While the current system provides a reliable and efficient solution, several advanced enhancements can be incorporated to further improve its performance, functionality, and adaptability in modern healthcare systems.

One of the key future directions is the integration of Internet of Things (IoT) technology, which would enable real-time data transmission to cloud platforms. This would allow doctors and hospital administrators to monitor multiple patients remotely through mobile applications or web dashboards. Such integration would also support centralized data management and analytics for improved decision-making.

Another important enhancement is the implementation of intelligent data processing techniques, including machine learning algorithms, to predict saline consumption patterns and provide early warnings before reaching critical levels. Predictive analytics can help in proactive healthcare management and reduce emergency situations.

Security and authentication mechanisms can be further strengthened by incorporating encrypted communication protocols and access control systems. This ensures that only authorized personnel can interact with the system, thereby maintaining data integrity and patient privacy.

The system can also be upgraded by integrating additional biomedical sensors such as heart rate monitors, temperature sensors, and blood pressure sensors to develop a comprehensive patient monitoring system. This would transform the proposed design into a multi-parameter health monitoring platform.

From a hardware perspective, improvements such as vibration compensation, temperature compensation for load cell readings, and the use of higher precision sensors can further enhance measurement accuracy. The addition of battery backup or power management systems can ensure uninterrupted operation during power failures.

Future versions may also include advanced user interfaces such as touchscreen displays, voice alerts, and multilingual support to improve usability. Features like automatic saline flow control using solenoid valves and integration with hospital information systems can further automate the treatment process.

Finally, the system can be scaled to support multiple saline monitoring units connected to a centralized control system, enabling efficient management in large hospitals. Such scalability will make the system suitable for smart hospital infrastructure and Industry 4.0-based healthcare environments.

Declarations

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Competing Interests Statement

The authors have not declared any conflict of interest.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors equally contributed to this study.

Informed Consent

Not applicable for this study.

Institutional Review Board Statement

Not applicable for this study.

Ethical Approval

Not applicable for this study.

Declaration of Artificial Intelligence

The authors declare that no artificial intelligence (AI) tools or AI-assisted technologies were used in preparing this manuscript.

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