Department of Electrical Engineering

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EE2044 - Electrical Measurements and Instrumentation

Mini Project

Smart Saline Monitoring System

G-22

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1. Introduction

Intravenous (IV) therapy is a common and critical medical procedure, specially in general hospital wards, where several patients receive saline infusions at the same time. However, IV administration is associated with considerable risks, including backflow of blood when the saline bottle runs empty, interruption of flow due to tubing kinks or folding, and the presence of air bubbles in the saline line. These issues have the potential to cause serious harm to patients if not addressed promptly.

This project proposes to develop a Smart Saline Monitoring System that detects and mitigates these risks through integrated sensors and actuators. The system includes liquid level detection for blood backflow prevention when the saline bottle runs empty, with an automatic shut-off mechanism using a servo-controlled clamp. Additionally, a flow rate sensor will continuously monitor the saline flow and activate an alarm when abnormal flow patterns are detected, such as blockages caused by tube folding. Furthermore, an air bubble detection system, which works on the principle of light refraction and reflection, will identify and alert healthcare professionals to any air space within the IV line.

By combining these features, the system will ensure real-time monitoring of IV saline administration with an automated intervention where necessary and enhance patient safety. This solution is designed to be cost-effective, easy to deploy, and capable of supporting continuous, accurate monitoring in busy hospital environments.

2. Literature review

Existing IV monitoring systems face limitations:

- Manual monitoring is error-prone (~20% flow rate inaccuracies).
- Commercial infusion pumps are costly and often lack integrated bubble detection.
- Prior academic projects used Arduino-based flow control but lacked LabVIEW integration and robust signal conditioning.

Recent studies highlight:

✓ Ultrasonic sensors provide non-invasive flow rate tracking (±2% error) but require vibration damping.

✓ IR-based bubble detectors offer cost-effective alternatives to ultrasonic sensors, though ambient light interference remains a challenge.

✓ Use of load cell enable precise fluid volume monitoring but need custom calibration.

This project improves upon prior work by:

- Designing a self-built IR bubble sensor with optimized signal conditioning.
- Integrating LabVIEW automation for real-time data processing and alerts.
- Combining three sensor types into a unified, low-cost system.

3. Market Review

Intravenous (IV) therapy is a very common procedure in hospitals, particularly in general wards where several patients are given saline infusions at the same time. Although saline administration seems to be straightforward, it poses very serious risks such as flow interruptions due to tube folding, undetected saline depletion, and the presence of air bubbles that can lead to life-threatening air embolisms. To assist in mitigating these dangers, several products have been developed, each addressing specific component of the problem.

For example, vTitan's Accuflow Drip Monitor is a gravity infusion monitoring system that gives real-time infusion rate and volume information. It includes remote monitoring at a central station and alarm for abnormalities. The system does not, however, detect air bubbles or automatic interventions like clamp actuation, limiting its potential to completely automate patient safety.

Shift Labs' DripAssist is another product that offers high-precision flow monitoring for gravity-based IV therapy. However, it is restricted to monitoring the flow rate only; it will not identify low saline levels or air within the IV line.

In summary, while current market offerings partially address the challenges in IV therapy monitoring, they are too expensive, and rarely offer an all-in-one solution. They lack integrated saline level detection, automatic clamp control, and cost-efficiency required for general ward use.

In contrast, the Smart Saline Holder proposed here integrates three important monitoring functions—detection of saline level by a load cell, flow rate, and air bubbles by an optical sensor based on the principle of refraction/reflection of light.

It is designed as a low-cost, standalone module that can operate independently of proprietary systems, and is particularly applicable to general wards and low-resource clinical settings. Its inclusion of automated alerts and physical intervention mechanisms further enhances patient safety and reduces the need for continuous human monitoring.

4. Objectives

The main objective of this project is to design and implement an IV (intravenous) saline monitoring and control system to enhance patient safety and minimize nursing workload in hospital wards. The system is aimed at mitigating typical risks related to IV therapy such as reverse blood flow, saline blockage, and air bubble entry. The specific objectives of the project are:

1. **Automatic Detection of Saline Level and Empty status**
    - To measure the weight of the saline bottle using a load cell and determine when the saline is about to finish.
    - To trigger a buzzer alarm as a warning when the level of saline goes critically low.
    - To disconnect the IV line automatically with a servo-driven clamp mechanism to prevent backward blood flow once the saline bottle is empty.
2. **Detection of Saline Flow Blockage**
    - To monitor the saline flow rate using a flow sensor and detect conditions when the flow is abnormally low or zero.
    - To alert hospital staff by a buzzer alarm and display the current flow rate on a display for convenient tracking.
3. **Custom Air Bubble Detection System**
    - To design and implement a custom-built air bubble detection device based on the principle of refraction and reflection of light.
    - To utilize this sensor to detect the presence of air bubbles in the IV line, which can pose serious risks to the patient.
    - To activate a buzzer alarm in case air bubbles are found, enabling prompt action and preventing potential air embolism.
4. **Real-Time Monitoring and Display**
    - To facilitate a real-time display of saline flow rate, bottle level status, and alert messages on a user interface.
    - To ensure clear visibility and easy interpretation of the system's status by medical staff in a hospital setting.

5. Project Scope

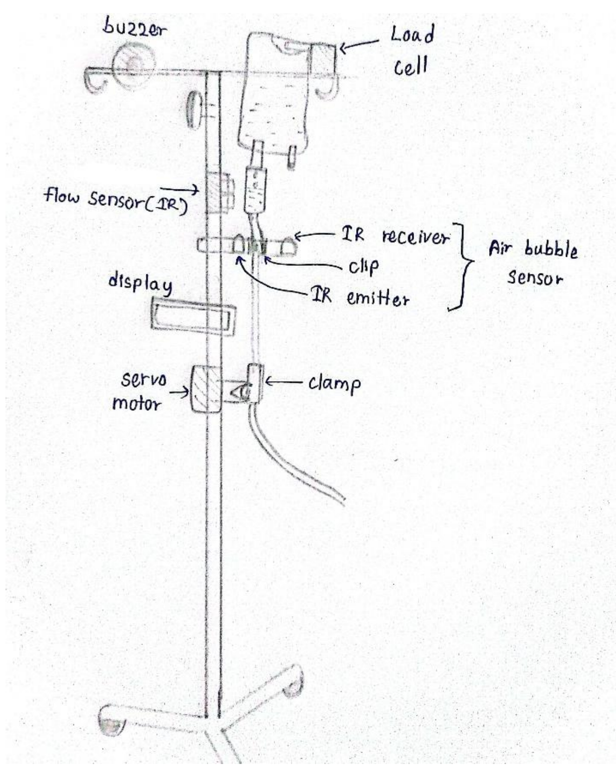
This project focuses on the design and development of a Smart Saline Monitoring and Control Holder to enhance patient safety during IV therapy. The system will include:

- Saline flow monitoring using a IR flow sensor to detect blockages.
- Air bubble detection using an optical sensor integrated with LabVIEW and a DAQ card for real-time calibration and processing.
- Fluid level monitoring using a load cell to estimate the remaining saline.
- Automated control of fluid flow using a servo-operated clamp mechanism controlled by Arduino.
- Visual and audible alert system to notify medical staff of any abnormal conditions.
- Modular design to attach sensors and control units to IV stands.

The scope of this project does not include redesigning saline bottles or custom tubing. Future extensions can look on central nurse dashboard integration.

6. Methodology

Diagram of the system setup



Liquid level detecting sensor and implementation

An empty or nearly empty IV saline bottle can lead to backward blood flow, which causes a potential health risk to patients. As a solution for that problem, this Smart Saline Holder includes a load cell-based weight monitoring system that acts as both an alert and automatic safety mechanism.

We propose to use a load cell sensor to continuously measure the weight of the saline bottle, as a direct indicator of the liquid level. The underlying principle is simple:

- When the saline bottle is full, it applies a higher downward force, resulting in a higher signal output from the load cell.
- As the saline is dispensed, the volume decreases and the weight gradually reduce.
- Once the weight falls below a predefined threshold (indicating an empty or nearly empty bottle), the system recognizes it as a critical condition.

The load cell output is passed through an amplifier and the analog signal is fed into the DAQ card. From there, the signal is processed in LabVIEW, which performs real-time monitoring and analysis. The LabVIEW interface:

- Displays the current saline weight
- Triggers a buzzer alarm when the threshold is crossed
- Sends a control signal to a servo motor, which activates a mechanical clamp to close the IV line and prevent backward blood flow

Flow Rate Detection Sensor and Implementation

An interrupted or abnormally slow saline flow—typically caused by tube folding, patient movement, or accidental blockage—can disrupt normal intravenous therapy and compromise patient safety. To mitigate this, the Smart Saline Holder integrates a flow rate detection system using the TCRT5000 infrared (IR) reflective sensor, which serves as an early warning mechanism for flow anomalies.

The TCRT5000 operates on the principle of infrared reflectance:

• It emits an infrared beam, which is reflected by the moving saline within a transparent IVtube.

• As the saline flows, microscopic air-liquid interfaces and tiny disturbances along the fluid path determine the amount of reflected light.

• The sensor detects such variations as an analog signal depending upon the status of flow.

The sensor output is passed through a signal conditioning circuit and fed into the DAQ card, where it is processed in LabVIEW. By analyzing the signal frequency and amplitude of the signal:

• Continuous flow can be differentiated from partial or complete obstructions.

• Sudden drops or absence of modulation indicate low or stopped flow conditions.

Within LabVIEW, the system:

• Provides a real-time visual representation of the saline flow status

• Activates a buzzer alarm once the flow drops below the expected level

• Enables early detection of critical interruptions, minimizing the need for constant manual monitoring

Although the TCRT5000 does not directly measure quantitative flow rate in units like mL/min, it effectively enables qualitative flow monitoring. When properly calibrated, the sensor can indicate relative flow conditions such as "normal," "slow," or "blocked," making it a cost-effective and practical solution for ward-level IV monitoring systems.

Air Bubble Sensor Design & Implementation

Presence of air bubbles in the IV line can pose serious risks to the patient such as air embolism. This sensor will detect air gaps and act as a safety mechanism in the Smart Saline Holder. We propose a non-contact, optical air bubble detection system based on the principle of light refraction and reflection.

Main Components:

- IR LED (Transmitter)
- IR Photodiode (Receiver)
- Tube Holder Clip (to hold the IV tube between the transmitter and receiver)

The system detects air bubbles based on how light behaves differently when passing through fluid vs air inside the tubing:

When IV fluid flows normally, it refracts and absorbs some amount of the IR light.

When an air bubble passes, the IR light is either reflected more strongly or passes differently, causing a sudden spike or drop in the light intensity at the receiver.

We can identify sudden deviation using LabVIEW. If a bubble is detected, Arduino command triggers an alarm using buzzer and automatic flow cutoff happens.

7. Timeline

Week 1	Research &Component testing Finalize project design and features
Week 2	Sensor integration and calibration
Week 3	Implementation of actuator system & alert mechanism
Week 4	Assemble of full system
Week 5	Final testing and adjustments

8. Conclusion

The proposed Smart Saline Monitoring system presents a practical and cost-effective solution to improve patient safety and reduce medical risks associated with IV therapy. By implementing a sensor-based system and automated actuator response, the system offers timely detection of flow issues, air bubbles, and empty saline levels. Its compatibility with existing hospital infrastructure ensures ease of adoption, while its modular design enables future scalability. This project addresses a real clinical need and also effective as an application of automation in healthcare.

9. References

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