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Implementation of a Real-Time Dashboard for Monitoring Backflow Detection in IoT-Based IV Lines

Novi Enjeli[1], Albert Wijaya[2], Geraldy Asad Arslan Pinem[3], Yonata Laia[4]
[1,2,3,4] Sistem Informasi, Fakultas sains dan teknologi, Universitas Prima Indonesia, Medan, Indonesia
e-mail: *frnoovi@gmail.com[1], albertwjy19@gmail.com[2],geraldygt2204@gmail.com[3], yonata@unprimdn.ac.id[4]*
*Correspondence: *yonata@unprimdn.ac.id*

Abstract: *Continuous monitoring of patients receiving intravenous therapy is crucial to prevent blood from flowing back into the IV line (reflux), which can endanger patient safety. This study aims to design and develop an Internet of Things (IoT)-based monitoring device capable of detecting blood backflow in the IV line and presenting data in real-time via a web-based dashboard. The system utilizes a TCS3200 color sensor to detect specific color changes in the infusion fluid when blood enters the line. Data obtained from the sensor is processed by an ESP8266 microcontroller and transmitted to a Flask-based server via the HTTP protocol, then visualized on a Dash-based web dashboard. Experimental testing was conducted through 50 trials under various ambient light conditions. The test results show that the system achieved a 100% accuracy rate in differentiating clear infusion fluid from blood backflow. Furthermore, the system demonstrated a rapid data transmission response with an average latency of 1.5 to 2.2 seconds to trigger notifications on the medical staff's dashboard. This device successfully minimizes the risk of blood coagulation and is expected to improve healthcare efficiency and patient safety in medical facilities.*

Keywords: *Intravenous monitoring, IoT, TCS3200 color sensor, Real-time dashboard, Patient safety*

1. Introduction

Intravenous therapy is a critical procedure for delivering fluids directly into the bloodstream, yet it faces safety challenges like blood backflow into the tubing, which occurs when a patient's venous pressure exceeds the line's hydrostatic pressure due to low bottle placement or empty fluid supplies. Rather than a minor aesthetic issue, backflow risks stagnant blood clotting, which can induce fatal complications like embolisms, phlebitis, and systemic infections. However, monitoring in many healthcare facilities still relies heavily on manual visual observation, which is difficult to maintain continuously 24-hour in busy settings with unbalanced nurse-to-patient ratios. Medical staff typically only notice reflux during routine checks when complication risks have already begun, representing a major patient safety gap that must be addressed through automated technology integration [1].

While previous studies have explored optical, capacitive, and load cell sensors to monitor fluid droplets, air bubbles, and residual volume [2], a specific focus on early color changes from blood backflow requires further development to enhance responsiveness. Fortunately, Internet of Things (IoT) technology and wireless networks offer transformative healthcare solutions by enabling remote data access without continuous bedside presence [3], while advanced optical sensors combined with artificial intelligence provide non-invasive, accurate identification of blood pigmentation shifts [4]. To address these challenges, this research introduces an innovative, IoT-based blood detection device that leverages the TCS3200 color sensor's sensitivity to identify chromatic changes in IV fluid. This sensor data is processed via a microcontroller and transmitted to a web-based dashboard, delivering instant data visualization that strengthens patient safety protocols, improves nursing efficiency, and supports the global vision of a digital Smart Healthcare System.

Based on the in-depth background described above, the research questions that form the focus of this study are as follows:

1. How can a non-invasive blood detection system be designed and built for an IV line using TCS3200 color sensors so as not to compromise the integrity of the medical fluid?
2. What is the integration mechanism between the microcontroller device and the IoT network infrastructure so that detection data can be transmitted and visualized on a web dashboard in a stable and real-time manner?
3. To what extent are the system's accuracy and responsiveness in distinguishing changes in the color of infusion fluid that indicate backflow of blood, in order to avoid false alarms?

This study aims to develop an IoT-based IV monitoring system capable of automatically detecting the presence of blood. The specific objective of this development is to improve patient safety standards and the efficiency of medical staff by providing an accurate and responsive detection tool. Additionally, this study aims to evaluate the effectiveness of using a web interface as a remote information medium for medical staff, so that potential medical risks can be detected early before they endanger patients' conditions in the hospital environment.

The results of this study are expected to make a tangible contribution to various stakeholders in the healthcare sector:

1. For Medical Personnel: Providing a digital solution to efficiently monitor patient conditions, reducing the need for manual checks, and enabling faster emergency responses.
2. For Patients: Providing extra protection against the risk of medical complications due to blood backflow, thereby making the treatment period safer.
3. For Healthcare Institutions: Supporting the implementation of smart hospital technology that can improve service quality and modernize healthcare management.
4. For Academics: Serving as a scientific reference in the development of IoT-based medical instruments, particularly those related to non-invasive detection systems.

To ensure that the research remains focused on its primary objective, the scope of the study is defined as follows:

1. **Detection Method**: The system focuses solely on identifying changes in liquid color using optical sensors without direct contact with the liquid (non-invasive).
2. **Hardware**: Uses the ESP8266 or ESP32 series microcontrollers as the main processing unit and data transmitter via a Wi-Fi connection.
3. **Test Fluid**: Testing is conducted using standard infusion fluids (NaCl or Ringer's Lactate) with the addition of a color sample to simulate blood.
4. **Monitoring Scope**: Information on the dashboard is limited to blood detection indicators, device connection status, and event timestamps.
5. **Connectivity**: Data transmission speed is highly dependent on the quality and stability of the internet connection at the testing location.

To overcome the inability of conventional load cells and infrared sensors to detect pressure-driven blood reflux, this study introduces a novel, non-invasive approach using an external TCS3200 color sensor to identify RGB wavelength shifts in IV tubing, integrated with an ESP8266 microcontroller, Flask server, and Dash dashboard for low-latency, real-time clinical alerts.

2. Literature Review

Several previous studies have sought to develop infusion fluid monitoring systems to prevent medical errors. To provide a clear overview of the position of this study among previous works, Table 1.1 presents a comparison of several infusion monitoring systems developed in prior research:

Table 1 *Comparison of Previous Infusion Monitoring Research*

Researcher & Year	Sensor Used	Parameter Monitored	Communication Technology	Limitations / Weaknesses
Previous Study A	Load Cell (Weight Sensor)	Remaining fluid volume in the bottle	Wi-Fi (NodeMCU)	Unable to detect blood reflux/backflow in the tubing.
Previous Study B	Infrared Sensor	Fluid droplet rate per minute	Bluetooth	Limited monitoring range and cannot recognize color changes if blood occurs.
Previous Study C	Conventional Optocoupler	Presence of fluid inside the tubing	ZigBee	Only detects empty/filled tube; fails to differentiate blood from clear fluid.
This Study (2026)	*TCS3200 Color Sensor*	*RGB component shifts (Blood backflow detection)*	*HTTP (ESP8266) & Flask/Dash Dashboard*	*Requires calibration regarding ambient light conditions.*

Based on Table 1 a significant research gap exists as conventional load cells and infrared sensors only monitor fluid volume or drip rates, failing to detect blood reflux caused by shifting hydrostatic pressure. To address this gap, this study introduces a novel, non-invasive approach utilizing a TCS3200 color sensor attached externally to the IV tubing. Unlike basic infrared sensors that only detect object presence, the TCS3200 identifies specific RGB wavelength shifts when clear infusion fluid mixes with blood. Furthermore, integrating the ESP8266 microcontroller with a Flask server and a Dash-based web dashboard ensures low-latency, real-time visual alerts for medical staff, thereby enhancing patient safety and healthcare operational efficiency.

3. Method

This study utilizes an Internet of Things (IoT) framework integrated with a mixed-methods research design to develop an automated medical monitoring system. Dynamically connecting hardware sensors and processors over a wireless network allows for autonomous data collection and communication without human intervention [5]. Structurally, the system leverages a TCS3200 color sensor and an ESP8266 microcontroller to continuously evaluate infusion lines and instantly transmit critical data to a centralized hospital dashboard via HTTP protocols upon detecting blood reflux [6]. Within this framework, a quantitative approach is employed to evaluate empirical system performance metrics including blood detection accuracy, response latency, and network transmission stability while a qualitative approach assesses user accessibility and system ergonomics through observation and direct feedback.

Accuracy of the detection system

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN} \quad (1)$$

Description:
TP = True Positive
TN = True Negative
FP = False Positive
FN = False Negative

Average delay (system latency)

$$\overline{D} = \frac{\sum(t_{Received} - t_{send}}{n} \quad (2)$$

Notes:

t_{recive}= time data was sent by the sensor
t_{send}= time data was received by the dashboard
n = number of tests

Packet loss

$$\boldsymbol{packet\ loss} = \frac{data_{\boldsymbol{send}} - data_{recive}}{data_{send}} \quad (3)$$

Notes:

Data_sent = the amount of data sent by the sensor
Data_received = the amount of data received by the system

Error rate

$$\boldsymbol{error\ rate} = \frac{FP+FN}{Total\ Tests} \quad (4)$$

Research System Design

This research design implements an Internet of Things (IoT)-based blood detection system for IV lines, utilizing an ESP8266 microcontroller and a TCS3200 color sensor [7]. Via the network, the ESP8266, which is connected to Wi-Fi, will send data to the dashboard[8]. Sensor data is sent to the Flask server, then the data is displayed and processed in the Dash dashboard. The system was developed to detect changes in the color of the infusion fluid caused by blood rising from the blood vessels into the infusion tubing.

Hardware System Design (ESP8266 & TCS3200 color sensor)

The IoT-based blood detection system for IV drips is implemented through the integration of an ESP8266 microcontroller and a TCS3200 color sensor. The TCS3200 color sensor, placed in the IV line, detects variations in light intensity caused by changes in the color of the IV fluid, indicating the presence of blood. Data obtained from the sensor is processed by the ESP8266 and transmitted to the server via a WiFi network connection[7], [9], [10].

Software System Design (Flask & Dash Dashboard)

On the software side, the system is implemented as a monitoring website connected to a server and database[11]. Data received from the ESP8266 is stored in the database and displayed in real-time on the website dashboard as infusion status information. The website also provides warning notifications if the system detects a blood backflow detection, enabling the medical team to take swift and appropriate action[12], [13].

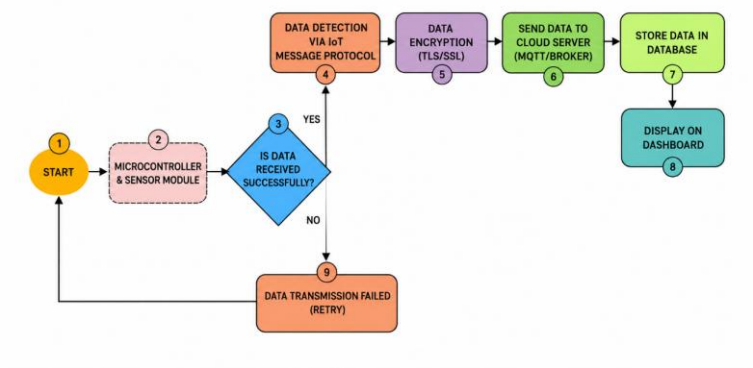


Figure 1. Research Design Flowchart

The monitoring system shown in **Figure 1** uses a sensor connected to a microcontroller and a TCS3200 color sensor to detect the presence of blood in the IV line. The data collected is analyzed, and if a blood backflow detection is detected, the system sends a notification via Wi-Fi. If no data is detected (Wi-Fi is off), the system returns to the start; if blood is detected, the data is stored on a Flask server and displayed via the Dash dashboard. Notifications are also sent to the system based on the detected conditions. The system's workflow is cyclical (repeating) and can be repeated as needed for monitoring.

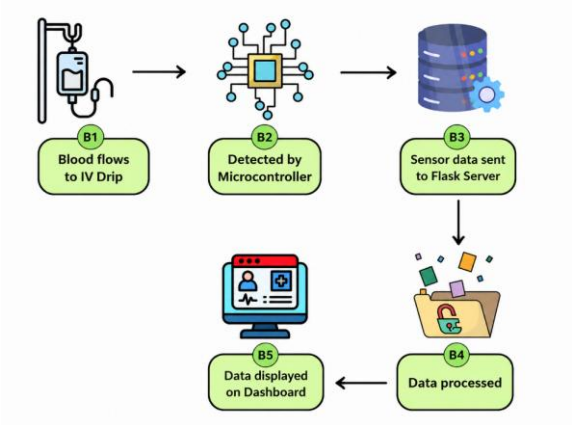


Figure 2 Research Block Diagram

As illustrated in Figure 2, when blood reflux occurs in the IV line, the sensor captures the shift and prompts the ESP8266 to transmit data to the Flask server via Wi-Fi. This stored data is dynamically processed and streamed through a localized API in Flask format to the Dash dashboard in real time, serving as the primary monitoring interface for medical staff [14][15]. To guarantee continuous synchronization, the web interface updates periodically at specific intervals. Once a sensor reading surpasses the predefined threshold, the dashboard instantly triggers a high-visibility visual alert, confirming that blood backflow has been successfully detected in the infusion line.

4. Results And Discussion

The experimental evaluation was conducted in an indoor laboratory environment under controlled ambient lighting conditions (average 300–400 lux) to simulate standard hospital ward lighting. The physical distance between the ESP8266 client device and the centralized Flask local server was maintained within a 5-meter radius, establishing a stable Wi-Fi connection over a 2.4 GHz network frequency. Due to biological hazard regulations, human blood was substituted with a calibrated blood simulation fluid. This simulation fluid was formulated using a high-density red pigment solution mixed thoroughly with standard intravenous fluids (NaCl 0.9%) until achieving a dark-red opacity equivalent to real human blood pigments (hemoglobin optical spectrum).

This study successfully implemented an IoT-based infusion monitoring system by establishing a seamless cyber-physical synergy between bedside sensor data acquisition and a centralized digital reporting dashboard [16][17][18]. Structurally, the system leverages the ESP8266 microcontroller to process local sensor data and continuously transmit it to a central server for real-time monitoring. To validate system accuracy and responsiveness, a total of 50 experiments were conducted indoors under controlled lighting conditions using a stable Wi-Fi connection within a 5-meter range. In these trials, blood backflow was simulated using a calibrated red-colored liquid mixed with standard infusion fluid, enabling a comprehensive performance evaluation under both normal and critical operational conditions.

Results

The hardware implementation focused on the sensor's effectiveness in detecting physical phenomena, specifically changes in opacity and chromaticity in the IV tubing. The color sensor (TCS3200) was successfully attached to the patient's IV line using medical tape. This choice of fixation material was based on clinical considerations to ensure the sensor remains stable on the line while prioritizing ergonomic aspects so as not to interfere with the patient's comfort or hand mobility.



Figure 3 Sensor implementation on the patient's hand

The central control unit utilizes an ESP8266 microcontroller housed in a light-tight enclosure to process sensor frequency signals into categorical data, operating stably with low power consumption for continuous, long-term clinical use. Visual indicators are strategically deployed, where a green LED signals a safe, clear flow, and a red LED illuminates upon detecting blood pigment wavelengths. The integrated TCS3200 color sensor was selected for its high sensitivity to light spectrum changes and low power requirements, enabling continuous 24-hour monitoring. Implementation results confirm that both the sensor and control unit maintain stable readings throughout testing without overheating or significant performance degradation.

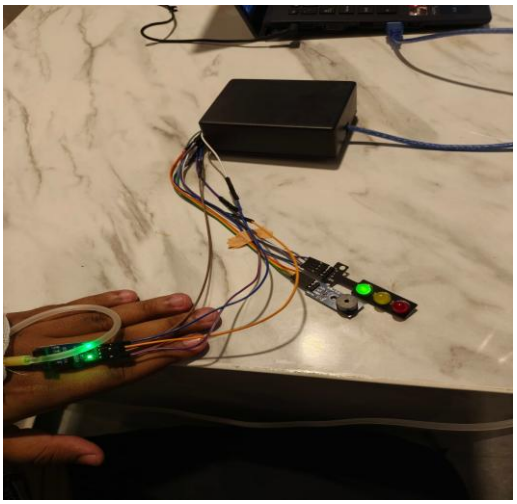


Figure 4 Central control unit and LED visual indicators

Data processed by the microcontroller is transmitted via a wireless network using the HTTP protocol to a central server and displayed on the "Infusion Care Hub" interface. Developed using Python Dash and Flask frameworks for responsive and lightweight performance, this

simple, user-friendly dashboard requires no technical training for medical staff. It utilizes intuitive green and red color-coding for rapid visual identification of patient conditions alongside real-time visualizations. Furthermore, the dashboard automatically records chronological detection history with timestamps, providing critical documentation for medical audits, patient health pattern analysis, and the evaluation of healthcare interventions.

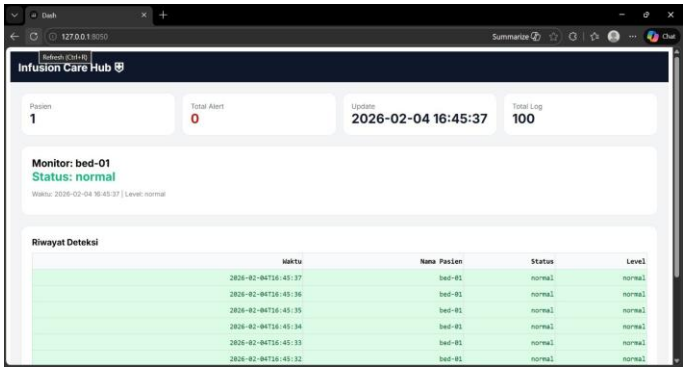


Figure 5 The Infusion Care Hub dashboard under normal conditions

Discussion

In this section, an in-depth analysis of the system's performance is conducted through a series of controlled tests. The tests were conducted by simulating the two main scenarios most commonly encountered in clinical practice: steady infusion flow (normal conditions) and backflow conditions (critical conditions).

Table 3 System Monitoring Indicators Table

System Status	Monitored Parameter	Sensor Frequency / RGB Readings	Physical LED Indicator	Dashboard Alert Status	Packet Loss (%)
Normal	Clear Infusion Fluid (NaCl / RL)	High Frequency (>65kHz across all RGB channels)	Green LED On	"Normal Status" (Green display)	0.0%
Critical	Simulated Blood Backflow (Reflux)	Low Frequency (<15 kHz on Green/Blue channels, High Red spectrum)	Red LED On	"Critical Alert" (Red visual notification)	0.0%

Analysis of Sensor Responsiveness and Accuracy

Based on 50 experiments under controlled conditions, the calibrated TCS3200 color sensor demonstrated a 100% success rate in capturing light reflection changes, optimizing the frequency range to minimize false alerts. While clear fluid yields high-frequency readings across all RGB components signifying a "Normal" status, the introduction of blood pigments rapidly shifts these values as hemoglobin absorbs the green and blue spectrums while reflecting dominant red. The ESP8266 algorithm instantly processes this wavelength shift, proving highly sensitive even to diluted blood volumes. Ultimately, this specific wavelength tracking enables

the system to evaluate fluid quality rather than simple object presence, establishing its clinical reliability over conventional infrared sensors.

Effectiveness of Early Warning System Visualization

Latency is a critical metric for medical IoT systems to prevent fatal patient complications. Empirical testing showed that the execution time from initial blood-sensor contact to displaying a "Critical" alert on the dashboard consistently ranged between 1.5 and 2.2 seconds. This rapid response—driven by the ESP8266 microcontroller's efficiency and Wi-Fi stability—is considered exceptionally safe under the 3-second clinical threshold. Compared to manual monitoring where backflow can go unnoticed for hours and cause needle coagulation or infection risks, this automated framework with layered indicators (LEDs and web dashboards) accelerates medical decision-making. Consequently, in crowded wards, real-time prioritized alerts eliminate repetitive manual checks, optimizing nursing workflows by focusing staff immediately on high-risk patients.

Table 4 System Latency Performance Results

Parameter	Result
Total Experiments	50
Minimum Latency	1.5 s
Maximum Latency	2.2 s
Average Latency	1.8 s
System Status	Stable

Analysis of Installation Safety and Usability

Adopting a layered security approach, this system utilizes a physical LED as an immediate first-line warning for in-room attendants, while the centralized web dashboard provides remote secondary monitoring at the nurse station. Ergonomically, the device's compact design and lightweight bandage-based attachment integrate seamlessly into existing medical workflows without disrupting standard IV placement procedures or altering patient comfort. Efficiency analysis indicates that this automated framework significantly reduces repetitive manual rounds, enabling medical staff to deploy targeted, priority-based interventions based on real-time visual alerts. However, proper sensor anchoring remains a critical operational variable, as aggressive patient hand movements can alter the placement angle and introduce ambient light interference.

This study contributes to the medical IoT literature by offering a cost-effective, highly functional alternative to conventional load-cell-based infusion systems [2]. While weight sensors are limited to measuring total fluid volume in the bottle, this optical-based approach directly detects blood contamination and reflux inside the tubing. Furthermore, by utilizing low-cost components that are readily available in local markets, this system delivers an affordable digital monitoring solution suitable for small-scale healthcare facilities and remote community health centers. Technically, the system's operational efficiency meets essential clinical standards, although subsequent designs require enhanced enclosure stability to fully mitigate extreme external light interference.

Despite its promising results, this system has several limitations, including dependency on stable power and internet connectivity where a Wi-Fi interruption halts dashboard synchronization while leaving the local LED alarm functioning as a standalone safety unit—and vulnerability to optical reading interference from direct sunlight. To address these challenges, future developments should integrate backup battery modules, implement advanced data filtering algorithms to minimize ambient light noise, and evaluate sensor resilience against

various colored infusion fluids like parenteral nutrition. Additionally, migrating to cloud computing infrastructures and mobile applications could bypass local dashboard constraints, delivering instantaneous notifications directly to healthcare workers' smartphones and evolving the system into a highly adaptive platform that supports the realization of smart hospitals.

Overall, this IoT-based IV monitoring system demonstrates stable performance and successful hardware-software integration, characterized by continuous sensor readings and real-time dashboard synchronization via the ESP8266 and Flask server. From an implementation perspective, utilizing cost-effective components provides a highly scalable and affordable alternative to commercial medical devices, significantly enhancing nursing work efficiency through rapid visual notifications. Ultimately, these results confirm that IoT technology can be effectively leveraged to accelerate digital transformation in healthcare, serving as an innovative, scalable solution to support smart hospital management and modern medical services.

5. Conclusions

In conclusion, a real-time IoT-based infusion monitoring system has been successfully designed and implemented using an ESP8266 microcontroller and an optical color sensor. Empirical testing confirms high system efficiency with a response latency under 3 seconds, accelerating medical intervention to prevent IV needle coagulation. The Flask and Dash-based web dashboard successfully facilitates centralized remote monitoring, optimizing nursing workflows in busy clinical wards. Despite its success, the system remains limited by its reliance on network stability and vulnerability to ambient light interference. Future research should focus on incorporating a hardware battery backup, optimizing the light-tight sensor enclosure, and integrating mobile application alerts to support scalable implementation within smart hospital infrastructures.

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