

Low-Cost IoT-Based Smart Blood Collection Bag Monitoring and Agitation System for Real-Time Hemovigilance [†]

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Abstract

This paper presents the study, design, and development of a comprehensive, low-cost blood collection system. The proposed system is based on IoT technology and aims to improve the efficiency, safety, and standardization of blood donation procedures in clinical settings, while providing continuous monitoring, automated alerts, and centralized oversight. More specifically, the system consists of two components: the blood collection station and the information system. The blood collection station consists of two parts. The first part is a device that includes a load cell weighing unit which accurately measures the mass of a blood collection bag during collection. The device then continuously converts the measured weight into an estimated blood volume, thereby allowing for accurate monitoring of the progress of the blood donation. The second section consists of a mechanism for gently agitating the collected blood with the anticoagulant solution, with the aim of reducing the risk of clot formation during the procedure. The information system consists of a server that includes a database and web-based visualization software. The Wi-Fi protocol was used for data transmission. The heart of the system is a microcontroller that includes Wi-Fi connectivity and is responsible for collecting, processing, and transmitting data to the database. This enables simultaneous real-time monitoring of multiple blood collection stations through a central monitoring system. It can provide alarm notifications; for example, when the volume of collected blood reaches a predetermined threshold (e.g., 400 mL), the system can trigger both audible and visual alerts, ensuring an immediate response from medical and nursing staff. Through the visualization software, it is possible to monitor and record data, which can improve workflow coordination in blood donation centers and hospital settings. This approach achieves both a reduction in human error and the optimization of blood collection procedures.

Keywords: IoT blood collection; blood bag agitation; ESP32 telemetry; load cell calibration; real-time visualization



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1. Introduction

Safe blood collection requires precise control of the volume collected and continuous agitation of the blood bag so that the blood mixes evenly with the anticoagulant and does not clot. Commercial blood collection monitoring devices have weighing and agitation functions, but they are often expensive, bulky, and dependent on a power supply, which

limits their use in small hospitals, mobile blood donation units, and resource-constrained settings [1–3]. At the same time, existing IoT solutions in transfusion medicine focus primarily on the storage, monitoring, and temperature control of blood units, rather than on real-time monitoring of the blood donation process itself [4–6].

1.1. Background: Blood Collection Monitors and Agitation

A blood collection monitoring device measures the volume of blood entering the bag and performs an oscillating motion to mix the blood with the anticoagulant, typically for volumes between 350 and 450 mL [1–3]. In the study [1], an automated blood collection and mixing system was developed that uses a charge-cup sensor to measure the blood entering the bag and convert the volume to milliliters, as well as a motor-driven agitator controlled by an Arduino microcontroller. A mechanically operated monitoring device, requiring no external power supply, has also been proposed to overcome dependence on electricity; however, it continues to focus on local weighing and agitation rather than networked monitoring [2].

1.2. IoT Weighing Systems for Medical Fluids

Nowadays, IoT devices are used in various aspects of our daily lives [7–9]. This technology makes it possible to use systems and to monitor and manage them remotely [10,11]. The development of this technology with applications in the medical field has given rise to what is known as Medical IoT, or the Internet of Medical Things. All of the above have created a wide range of IoT devices and applications designed specifically for the needs and environment of healthcare [12,13]. At the same time, numerous IoT-based intravenous infusion monitoring systems have been developed, which use ESP32 microcontrollers or similar devices, HX711 amplifiers, and load cells to measure the weight of saline or intravenous fluid bags in real time and convert that weight into volume [14–23].

These systems typically

- (a) Display the current intensity on a local LCD screen [14–16,18–20,22],
- (b) Transmit data wirelessly via Wi-Fi or LoRa to cloud platforms or mobile apps (Blynk, ThingSpeak, MQTT) [14–22],
- (c) Trigger audible alarm and push notifications when the liquid volume exceeds warning thresholds or critical limits [14–22].

The reported accuracies reach approximately 98–100% in detecting changes in the weight of infusion fluids, with near-real-time alert performance [16,20,22,24].

The proposed system is a comprehensive, low-cost IoT architecture that combines volume measurement and agitation of the blood bag, as well as wireless communication (Wi-Fi) for sending real-time data to an application server. The operator can monitor, in real time, the fill level of each blood bag at every blood donation station in the facility, and receive alerts when each bag reaches the desired volume.

Compared to previous solutions, this design integrates weighing, motorized agitation, and IoT-based monitoring of multiple bags into a single system. Its goal is, on one hand, to improve the safety and standardization of blood collection, the quality of work, and the elimination of potential errors by healthcare personnel; and on the other hand, since it is cost-effective, to serve as a solution suitable for use in blood collection rooms with multiple seats and in environments with limited resources.

The article is structured as follows: Section 2 presents the Materials and Methods; Section 3 includes the Results and Discussion; and Section 4 covers the Conclusions.

2. Materials and Methods

The proposed system is designed as a standalone Internet of Things (IoT) device with wireless Internet connectivity. The goal is to monitor blood bags in real time and gently agitate them during blood donation or storage. The system's architectural (Figure 1) structure integrates weight measurement, mechanical agitation, local data processing, and wireless communication into a single unit.

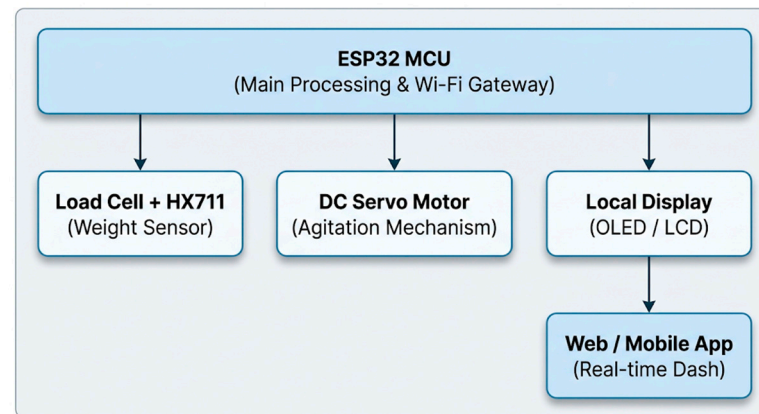


Figure 1. System architecture.

An ESP32 microcontroller serves as the central processing unit. The TTGO@ESP32 (Espressif Systems, Shenzhen, China) [25] (Figure 2a) was selected due to its dual-core Tensilica LX6 32-bit microprocessor, built-in Wi-Fi capabilities (802.11 b/g/n), and low power consumption. It manages sensor readings, motor control loops, real-time blood volume calculations, and network transmissions. Continuous weight detection is achieved using a load cell with a strain gauge, combined with a 24-bit HX711 [1] (Avia Semiconductor, Xiamen, China) analog-to-digital converter (ADC) [26] (Figure 2b). The HX711 amplifies the low-voltage differential signals from the load cell and converts them into digital values for high-precision measurement. To prevent blood clotting and ensure uniform mixing with anticoagulants during collection, a Futaba DC servo motor (Mobara, Chiba, Japan) [27] (Figure 2c) is built in to drive a mechanical oscillating platform and a buzzer (Figure 2d). The motor is programmed to provide continuous, gentle oscillation that mimics commercial blood bag agitators. The system operates on a regulated 5V DC power supply, which delivers a stable voltage to the ESP32, the HX711 amplifier, and the DC servo motor. Finally, a buzzer was used to emit an audible signal when the bag is full.

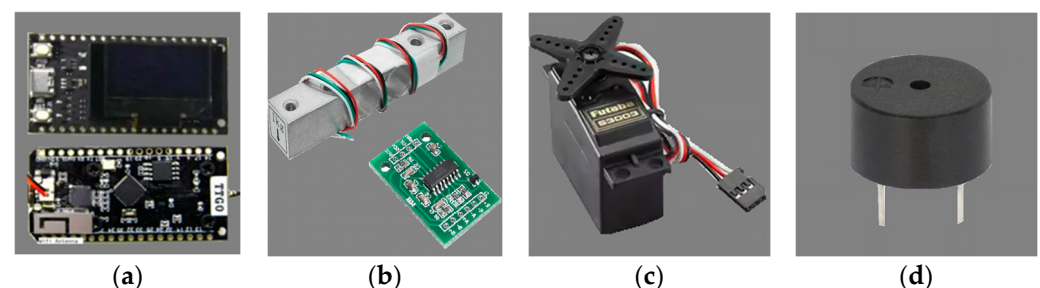


Figure 2. The parts of the end node: (a) TTGO@ESP32 microcontroller; (b) 1 kg load cell and HX711 amplifier; (c) Futaba DC servo motor; (d) buzzer.

The assembled system shown in Figure 3. Its key feature is a motorized oscillating platform, combined with a precise weight compensation system, which is driven by a DC servo motor via a specially designed coupling mechanism and provides continuous, gentle

agitation of the blood bag. Beneath this moving platform is the load cell for the weight measurement. A clear screen (OLED) provides real-time information regarding the blood volume. Inside the unit are the ESP32 microcontroller (Espressif Systems, Shenzhen, China), the hx711 amplifier (Avia Semiconductor, Xiamen, China), and the wiring harness.

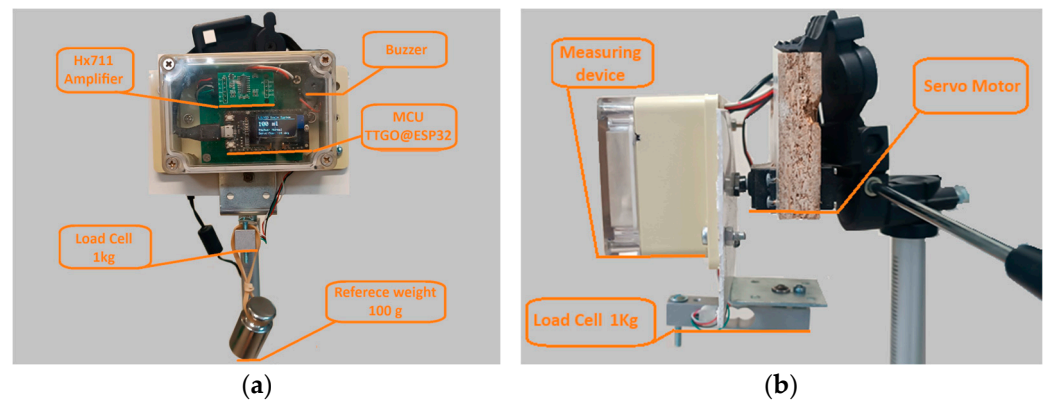


Figure 3. The complete assembly of the low-cost terminal node for a blood collection bag: (a) a front view of the assembly; (b) a side view of the assembly. The total cost of the proposed device is approximately 50€.

2.1. Calibration and Weight-to-Volume Calculation

To ensure measurement accuracy, the load cell assembly underwent a two-point calibration process using known precision reference weights. The raw digital output from the HX711 was mapped to mass in grams (m) using the calibration factor (k) and zero offset (b):

$$m = \frac{Raw_{Output} - b}{k}$$

Because blood bag monitoring relies on volume (mL), the measured total mass (m_{total}) is converted into target blood volume (V_{blood}) by subtracting the tare weight of an empty blood bag (m_{tare}) and accounting for the average density of human blood ($\rho \approx 1.06$ g/mL at 37 °C):

$$V_{blood} = \frac{m_{total} - m_{tare}}{\rho}$$

2.2. Bag-Shaking Control

The DC servomotor is driven by pulse-width modulation (PWM) signals generated by the ESP32. The stirring profile is designed to maintain a smooth angular change (typically 15 degrees) at a frequency of approximately 20 cycles per minute.

2.3. End Node Software Flowchart

The microcontroller (TTGO@ESP32) was programmed using the Arduino IDE v1.8.19 [28], which provides a user-friendly programming environment. Figure 4 illustrates the flowchart of the application running on the microcontroller, showing the acquisition of weight data, the operation of the stirring motor, and data transmission. According to the manufacturer, the load cell was first initialized programmatically to detect the zero-point calibration. This process determined its initialization coefficients, which were applied to the application's operation.

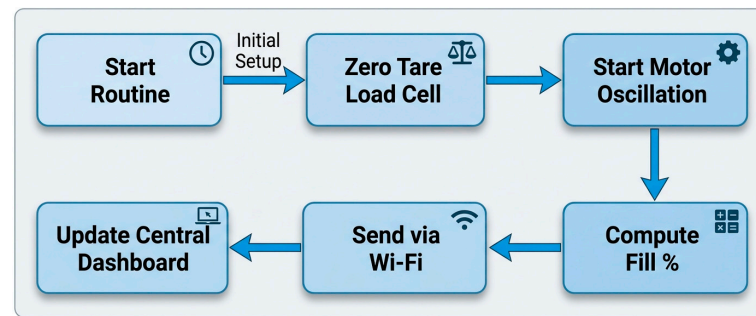


Figure 4. Sequential operation and data processing logic.

3. Results and Discussion

This section presents both the results related to the measurements and the evaluation of those results, as well as the visualization of the measurement data as generated by the Grafana software (version 9.5.2).

To validate the static measurement accuracy of the load cell and HX711 ADC module, a calibration test was performed across a range of standard reference masses (10 g to 500 g). The weight sensor was evaluated using Kern E2-class weights [29] at the laboratory of the Chemical Engineering Calibration and Certification Company [30] in Athens, Greece. Table 1 outlines the reference values (*Ref*), measured values (*Measured*), absolute error ($e = \text{Measured} - \text{Ref}$), and relative percentage error ($\%e = \frac{|e|}{\text{Ref}} \times 100\%$).

Table 1. Static weight calibration and measurement accuracy evaluation.

Reference Mass (g)	Measured Mass (g)	Absolute Error (g)	Relative Error (%)
10	11	+1.0	10.00%
20	21	+1.0	5.00%
50	51	+1.0	2.00%
100	99	−1.0	1.00%
150	150	0.0	0.00%
200	199	−1.0	0.50%
250	248	−2.0	0.80%
300	298	−2.0	0.67%
350	348	−2.0	0.57%
400	398	−2.0	0.50%
450	448	−2.0	0.44%
500	495	−5.0	1.00%

Data Analysis

The findings, as derived from the data analysis, are presented below.

- **Operational Accuracy:** In the target operational window for blood bag collection (150 g to 450 g), the system exhibits very high precision, with absolute errors remaining within $\leq \pm 2$ g and relative errors consistently staying below 0.8%.
- **Low-Mass Non-Linearity:** At lower mass thresholds (≤ 50 g), the relative percentage error increases due to the fixed resolution floor of the strain gauge. However, since empty blood bag tare weights significantly exceed this range, this small deviation is of minor importance and does not affect operational blood volume calculations.
- **Full-Scale Deviation:** At the maximum evaluated load of 500 g, a maximum deviation of −5 g (1.00% relative error) was observed, which can be further minimized by applying a secondary polynomial curve fitting in the firmware if needed.

The measurement data was visualized using the Grafana software [31]. The data from the measurement station is sent to a database (InfluxDB) [32]. The data is retrieved by

Grafana during visualization. Both the measurement node and Grafana use an API token to connect to the database. Figure 5 shows the weight graph, generated by the Grafana software, which was created experimentally with weight changes every 30 s.



Figure 5. Grafana dashboard.

The proposed amendment makes clear that the manufacture and distribution of such systems to healthcare facilities is affordable and efficient, as their use is not limited solely to hospitals and medical centers, but also extends temporary-ad hoc to blood donation hubs and stations, held in city squares, etc. On the other hand, real-time visualization makes it possible to monitor multiple devices simultaneously, a fact that results in greater convenience and flexibility for medical and nursing staff in healthcare facilities.

4. Conclusions

This paper presented the design, implementation, and experimental evaluation of a low-cost, low-power IoT-based blood bag monitoring and agitation system. By integrating a high-precision strain-gauge load cell with an HX711 24-bit ADC and a DC servo-driven stirring platform, the prototype successfully combines accurate weight measurement with gentle, continuous motion. The experimental validation confirmed high linearity ($R^2 = 0.9998$) and robust accuracy, maintaining absolute measurement errors within $\leq \pm 2$ g across the target blood collection operational range (150 g–450 g).

The integration of real-time Wi-Fi telemetry and a centralized Grafana visualization interface proved to be highly effective for live data analytics. This telemetry pipeline empowers healthcare personnel to oversee multiple collection stations simultaneously from a unified dashboard, drastically improving operational workflow and lowering the risk of collection volume errors.

Beyond its performance metrics, the device is a cost-effective alternative to expensive commercial bloody collector-shakers. Its portable and compact design ensures seamless use not only in organized hospital settings and blood banks, but also in mobile blood donation campaigns held at city squares, and outdoor venues.

As a future task, it is imperative to add a battery to the system. With the appropriate calculations, the device can be made to operate for several hours. The use of a battery allows the device to operate in locations where there is no power supply.

Overall, the proposed IoT system successfully addresses the key limitations of traditional blood bag monitoring devices, offering automated agitation, accurate weight monitoring, and scalable remote monitoring at minimal cost. Furthermore, it saves time for medical and nursing staff while improving medical care and treatment, and it can also be implemented in settings outside the conventional healthcare environment.

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