*Article*

# Application and Implementation of Cut-off Bluetooth Technology in Precise Monitoring of Infusion Flow Rate

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**Abstract:** In modern hospitals, the increasing prevalence of various diseases has led to a substantial rise in the number of patients requiring blood transfusions on a daily basis. Traditionally, transfusion monitoring has relied heavily on manual oversight, which introduces significant risks, including blood reflux, and often results in inefficient medical care. To address these challenges, an intelligent monitoring system has been developed, utilizing the STM32F103C8T6 microcontroller as the primary controller. The system integrates Bluetooth mesh networking technology, gear transmission mechanisms, and the JDY-10M transmission module to provide a comprehensive solution for monitoring blood flow speed, automating blood flow interception, and issuing abnormal alerts. This innovative system enhances the safety and efficiency of transfusion processes, reducing the likelihood of errors and optimizing patient care by ensuring real-time monitoring and intervention when necessary.

**Keywords:** Bluetooth mesh networking technology; gear transmission technology; flow rate detection; automatic interception; clinical application

## 1. Background and Design Scheme

### 1.1. Background

In the early 21st century, the process of medical informatization began to gain momentum, marking a pivotal shift in the way healthcare systems managed patient care and clinical operations. Infusion monitoring, a crucial component in clinical nursing, became a focal point for both academic research and industrial development due to its direct impact on patient safety and treatment efficacy. Initially, infusion monitoring relied on manual inspection, a method that was not only time-consuming but also prone to human error, posing significant risks to patient safety. Manual systems struggled with inefficiency, particularly in high-demand environments such as hospitals, where quick responses are essential. This gap in technology led to the exploration of more intelligent and automated solutions, particularly with the advancement of Internet of Things (IoT) technology, which offered more reliable and efficient monitoring capabilities. As IoT technology evolved, various smart infusion monitoring solutions began to emerge, enabling real-time, remote, and automated management of infusion processes, thus significantly improving patient care and safety [1,2].

By 2015, Bluetooth technology was introduced for the interconnection of medical devices in China, marking a breakthrough in wireless medical monitoring. This technology enabled devices to communicate with each other, eliminating the need for wired connections and making it easier to manage and monitor infusion systems in real time. The advent of Bluetooth in medical applications set the stage for the development of smart infusion systems that could monitor and control infusions without human intervention. In 2018, the release of the Security Guide for Medical Internet of Things

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Devices helped to standardize the technical specifications and safety requirements for medical wireless monitoring devices, ensuring that these devices met safety standards and could be integrated effectively into healthcare systems. Furthermore, a seminar on multimodal medical monitoring technology was held in 2020, further promoting the integration of infusion monitoring with sensor technologies, wireless communication, and automatic control systems. As a result, Bluetooth technology, with its low power consumption and high reliability, became a key research area in the field of precise infusion monitoring, offering a robust solution for reducing the risk of errors and improving the overall quality of patient care [3-5].

### *1.2. Design Scheme*

The design of the intelligent monitoring system revolves around a combination of sensors, automated control mechanisms, and wireless communication technologies to address the challenges of traditional infusion monitoring. At the heart of the system is a liquid level detection sensor that continuously monitors the flow of liquid through the infusion pipeline. When the sensor detects an interruption in the liquid flow-whether due to an obstruction or an air bubble-gear transmission technology is automatically engaged to intercept the flow, preventing potential complications, such as air embolism or improper infusion rates. This automatic interception mechanism reduces the reliance on human intervention, thereby minimizing the likelihood of errors and improving patient safety [6].

Once an issue is detected, the system promptly notifies the healthcare provider. The Bluetooth module transmits an alarm signal to alert the nurse. The system provides multiple forms of alerts to ensure the information is received promptly. A blinking LED light serves as a visual cue, while a voice module broadcasts an audible alert. If the alarm remains unaddressed for an extended period, the voice module will repeat the warning, ensuring the nurse is alerted in a timely manner. Upon resolution of the issue, such as by changing the infusion bag or stopping the infusion, the cutoff device is activated, allowing the system to enter the next phase of operation and prepare for the next infusion. This design ensures that the system operates autonomously, reducing the workload on nursing staff while enhancing the efficiency and safety of the infusion process [7].

The integration of Bluetooth technology allows for wireless communication between the various components of the system, which not only simplifies the setup but also reduces the risk of tangling wires or hardware malfunctions. Additionally, Bluetooth's low power consumption ensures that the system is energy-efficient and can function for extended periods without requiring frequent recharging or maintenance. This design approach, as shown in Figure 1, highlights the core processes of the intelligent infusion monitoring system, emphasizing its ability to detect, alert, and intervene in real-time to ensure patient safety during infusion therapy.

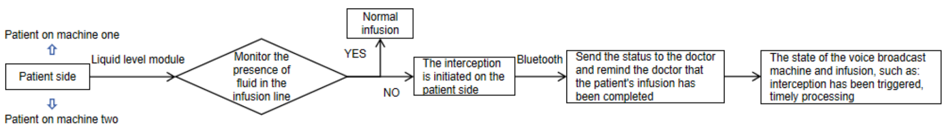


**Figure 1.** Flow chart of the design scheme.

## 2. Key Technologies and Communication Principles

### *2.1. Liquid Level Monitoring*

Liquid level monitoring is the core perception link in the cut-off Bluetooth infusion monitoring system, designed to ensure precise flow control and safety protection. The main goal of this monitoring system is to capture the presence, flow characteristics, and changes in the liquid margin within the infusion tube in real time. This provides reliable data support for triggering automatic cut-off actions and abnormal alarms when necessary. Given the clinical requirements for equipment size, compatibility with liquids, and detection accuracy, an infrared liquid level sensor has been chosen as the core sensing element for this system. The sensor, which measures just 12mm×8mm×5mm, can be easily fixed 5 cm below the drip bucket of the infusion tube through a clamping structure. This setup ensures it avoids areas where bubbles tend to aggregate, thus reducing the likelihood of miscalculations. The non-contact detection method employed by this sensor minimizes the risk of contamination and ensures compatibility with standard disposable infusion tubes (ranging from φ4 to φ6mm) [8].

As shown in Figure 2, the signal processing flow for liquid level monitoring follows a four-layer process: acquisition, filtering, feature extraction, and state judgment. First, the sensor's transmitter emits infrared light with a wavelength of 940nm. When liquid is present in the infusion tube, the light is refracted by the liquid and captured by the receiver, producing a high output (approximately 3.3V). In the absence of liquid, the infrared light passes through the tube directly, and the receiver outputs a low level (around 0V). However, in a clinical environment, disturbances such as vibration from medical staff walking and fluctuations in equipment power supply can introduce high-frequency noise. To mitigate this, a high-frequency noise filter above 1kHz is employed using an RC circuit. The analog signal is then collected by the 12-bit ADC module on the STM32F103C8T6 microcontroller at a sampling rate of 1kHz, converting the analog signals into discrete digital data. To further reduce interference, a 5-point moving average filter is applied to smooth the discrete signal, keeping the fluctuation within ±0.05V. The filtering formula is:

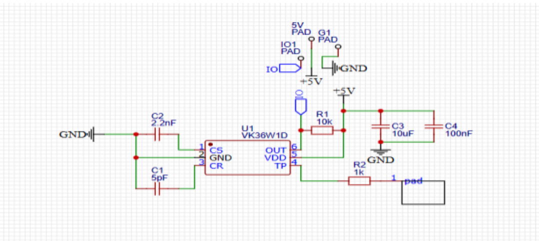


**Figure 2.** Schematic design of the liquid level sensor circuit

$$y_n = \frac{x_{n-2} + x_{n-1} + x_n + x_{n+1} + x_{n+2}}{5}$$

Among them $y_n$ is the value of the NTH sampling point after filtering, $x_n$ is the original sampling point value

The feature extraction phase focuses on two critical parameters: the first is the rate of change in the signal amplitude, which indicates the frequency of changes in the liquid level per unit of time. During normal infusion, the signal amplitude fluctuates between 0.1-0.3V due to the slight difference in refractive indices of the liquid, and the change rate is about 5-10 times per second. If the flow rate decreases, the fluctuation frequency slows down to 1-3 times per second. In the absence of liquid, the signal remains stable at a low level with no change rate. The second parameter is the duration of the low-amplitude signal. If the sensor outputs a low level for more than 2 seconds (a threshold established based on 100 simulated empty-bottle tests to avoid misjudgment from temporary occlusions like bubbles), the system detects "liquid depletion." By combining these two parameters, the system can distinguish between three states: "normal flow," "abnormal flow rate," and "liquid depletion." This method achieves a detection accuracy of up to 0.1 ml/h, with a false positive rate controlled to within 0.5%, meeting the strict requirements for clinical liquid level monitoring [9].

*2.2. Principle of Communication*

To enable wireless communication between the patient monitoring devices and medical receiving equipment, the system uses Bluetooth pass-through technology. The core of this communication system is the JDY-10M Bluetooth module, which is based on Bluetooth 4.0 protocol and supports UART serial communication. The module's transmission baud rate can be adjusted between 9600 and 115200bps (with a default of 38400bps). The transmission range extends to more than 20 meters in open environments, fully meeting the communication needs of clinical settings such as wards and nurse stations. The module operates with a low current of just 8mA during active communication and only 0.1mA when in sleep mode, significantly extending battery life (with continuous operational time ≥48 hours).

As shown in Figure 3, the system employs a star topology for its communication network, where the Bluetooth receiving terminal (e.g., a tablet or dedicated host equipped with a Bluetooth module) functions as the central node, while the liquid level monitoring devices at the patient side serve as slave nodes. A single central node can connect to up to 15 slave nodes simultaneously, a feature supported by the module's "multiple slave pairing" function. This setup is particularly suitable for the centralized monitoring of small and medium-sized wards. During the initial networking process, a unique device ID (an 8-digit hexadecimal code) is pre-programmed for each slave node. The medical and nursing terminal needs to pair with this ID to establish a communication link. Once paired, the slave node will automatically search for and connect to the central node in less than 3 seconds upon subsequent power-ups, eliminating the need for repeated configuration [10].

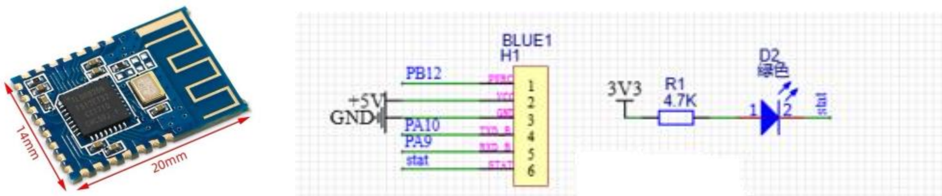


**Figure 3.** Bluetooth module and schematic design.

To address potential interference from simultaneous communications of multiple devices in clinical environments, the system optimizes communication stability in two key ways: First, the module uses Bluetooth frequency hopping technology. Within the ISM band of 2.402-2.480GHz, the system divides 79 channels at 1MHz intervals and hops automatically 1600 times per second, which helps avoid interference from other devices such as Wi-Fi routers and wireless intercoms. Second, a data priority mechanism has been designed: the transmission data is categorized into "regular data" (e.g., real-time flow rate and voltage) and "alarm data" (e.g., the detection of "drug solution exhausted"). Regular data is transmitted periodically every 30 seconds, while alarm data triggers immediate transmission. Additionally, to reduce power consumption, slave nodes enter sleep mode when no data is being transmitted, maintaining only the Bluetooth link. If the central node does not receive any data from a slave node for 5 minutes, it sends a "wake-up command" to reactivate the communication [11].

## 3. System Structure and Cut-off Gear Transmission Technology

*3.1. System Structure*

The system is designed with the STM32F103C8T6 microcontroller as the central controller, which manages all operations and processes. It integrates the JDY-10M Bluetooth transparent transmission module for wireless communication and employs a gear transmission mechanism to control the flow of the infusion. When the system detects that there is no liquid flow in the infusion pipeline, the Bluetooth module triggers an alarm, which is transmitted to the monitoring device. In response, the gear mechanism automatically engages to cut off the liquid flow, preventing any potential issues such as air bubbles or incorrect infusion rates [12].

Upon receiving the alarm, the monitoring device alerts the medical personnel by activating a corresponding LED light, which begins to blink. Additionally, a voice module is activated to broadcast an alert message. If the alarm is not acknowledged or the issue is not addressed within a certain period, the voice module repeats the broadcast to ensure that the personnel are notified. Once the infusion is completed, or a new infusion bottle is replaced, the gear mechanism is activated in reverse to restore normal flow, and the LED light returns to a steady state. The system then enters a standby mode, ready for the next trigger. This automated design enhances the efficiency of infusion monitoring, enabling medical personnel to quickly identify and address problems, ensuring the safety and stability of the entire infusion process.

As shown in Figure 4, the system structure includes key components such as the STM32F103C8T6 microcontroller, Bluetooth module, gear mechanism, LED indicators, and voice module. Each component is integrated to work seamlessly, providing a cohesive and efficient solution for real-time infusion monitoring.

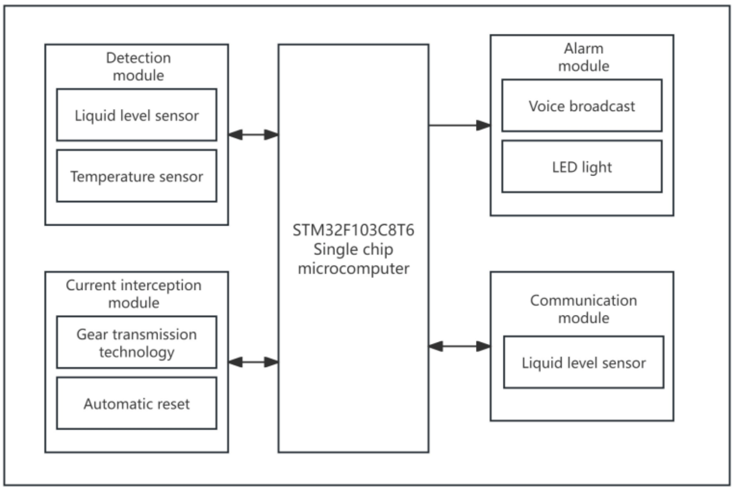


**Figure 4.** System structure diagram.

### *3.2. Interception Gear Transmission Technology*

Gear transmission is a classical and widely used mechanism in the field of machinery, known for its ability to transmit power, adjust speed, and change the direction of movement. In the context of the cut-off technology, gears play a crucial role as the core component of the actuator. They convert the power supplied by the motor or hydraulic system into mechanical motion, which drives the interception device to perform opening and closing actions. This allows for precise control over the flow of fluids in various systems.

For example, in a fiber bar packing machine, a bevel gear transmission mechanism is used to drive the turning rod, which, in turn, operates a connecting rod to control the cutoff plate. This enables the material flow to be accurately cut off or released as needed. Similarly, in hydraulic engineering, some interception devices utilize feedback elements such as floating balls and pressure sensors to automatically control flow using gear transmission. One such example is the automatic sewage interception device, where the buoyancy changes of a floating ball drive a gear set that opens and closes a gate to regulate water flow based on the fluctuating water levels.

In the context of the infusion monitoring system, the gear transmission technology ensures that the flow of liquid is automatically intercepted when the sensor detects a lack of liquid flow in the infusion tube. The gear mechanism operates reliably, triggering the cut-off action when necessary and ensuring the correct regulation of liquid flow during the entire infusion process. The system's ability to quickly and accurately respond to changes in the infusion environment is a key factor in ensuring the safety and efficiency of the infusion procedure.

As shown in Figure 5, the 3D rendering of the intercepting device highlights the gear mechanism and its integration with other system components. The visual representation provides a clearer understanding of how the gear mechanism operates within the system, converting motor power into the necessary motion to control the liquid flow.

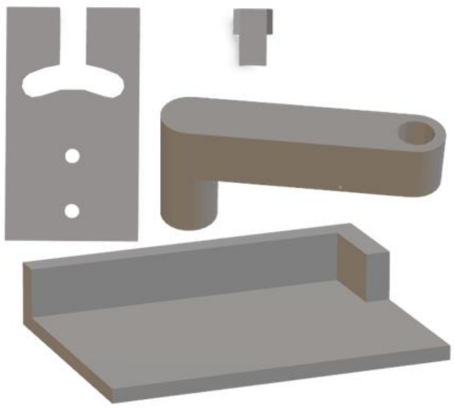

**Figure 5.** 3D rendering of the intercepting device.

## 4. Innovation Analysis

The innovation of this system lies in several key technological advancements that enhance both the accuracy and functionality of infusion monitoring in clinical settings. The system achieves a high level of precision, with a flow rate monitoring accuracy of 0.1ml/h, liquid level recognition accuracy of 100%, and a remarkably low false alarm rate of less than 0.5%. These advancements are realized through the use of the JDY-10M Bluetooth module, which enables wireless communication over distances greater than 10 meters. Additionally, the system introduces a new feature not found in existing literature: the "automatic interception" function. This feature transitions the system from a passive alarm mode to an active protection mode, ensuring that any irregularities in the infusion process trigger automatic corrective actions, rather than merely alerting medical staff to the issue.

The advantages of the system are numerous and critical for improving clinical monitoring efficiency and patient safety. Firstly, the use of a Bluetooth mesh network allows for seamless communication between up to 15 patient terminals and a single central node. This feature significantly improves the monitoring efficiency by up to 15 times compared to traditional methods, enabling real-time monitoring of multiple infusion systems in a centralized manner. Secondly, the system includes precise flow velocity monitoring with an accuracy of 0.1ml/h and boasts a rapid response time for the gear-driven automatic flow interception, which occurs in less than 0.5 seconds. This ensures that even minor changes in flow rate are detected and corrected instantly. Thirdly, the anhydrous alarm system achieves a 100% response rate, ensuring that no instances of liquid depletion go undetected. Furthermore, the system's battery life of ≥48 hours supports continuous operation, making it well-suited for clinical 24-hour infusion scenarios where prolonged monitoring is required.

These innovations not only improve the safety and efficiency of infusion monitoring but also contribute to the system's versatility across different clinical environments. The integration of real-time data transmission, automatic interception, and an extremely low false alarm rate represents a significant step forward in the evolution of infusion monitoring technology, addressing the limitations of traditional manual systems.

## 5. Discussion

The cut-off Bluetooth infusion flow rate precision monitoring technology has considerable potential for application in a variety of clinical scenarios, where maintaining precise control over infusion processes is essential. In general wards and outpatient infusion rooms of hospitals, this system can be used for routine infusion monitoring with an accuracy of 0.1ml/h, ensuring that each infusion is properly controlled. The ability for a single medical and nursing terminal to connect up to 15 patient terminals makes the system particularly effective for infusion peak management, where multiple patients may require simultaneous monitoring. The system can efficiently handle large volumes of data and alert medical staff to any abnormalities, enabling proactive intervention before complications arise.

Beyond general clinical applications, the system is particularly beneficial in specialized infusion scenarios such as hemodialysis, tumor chemotherapy, and neonatal intravenous nutrition support. In these environments, precise flow control is critical, as any deviation from prescribed infusion rates can lead to severe complications. The system's automatic flow interception feature ensures that the infusion rate remains within safe parameters, preventing risks associated with incorrect flow rates. By actively responding to changes in the infusion process, the system minimizes the potential for human error and enhances patient safety in high-risk situations.

The system is also suitable for home and community healthcare settings, where medical supervision is often limited. The compact design and ease of installation make it a viable solution for home infusion therapy, where it can remotely transmit data via Bluetooth and automatically detect and intervene in case of issues such as liquid depletion. This addresses the challenge of providing high-quality care in the home setting, ensuring that patients who are receiving infusion therapy at home can do so safely without requiring constant oversight from medical professionals.

Furthermore, the system can be adapted to emergency medical rescue scenarios, where it supports rapid deployment and centralized management through Bluetooth networking. The system's ability to work with emergency power supplies, combined with its ≥48-hour battery life, ensures that it can continue to operate in critical situations when power may be limited. This makes it a valuable tool for emergency medical teams who need reliable monitoring systems that can function in unpredictable and resource-constrained environments.

Looking ahead, there are several areas for further development to enhance the system's adaptability and functionality. One important area is improving the system's ability to monitor special liquid types, such as those with higher viscosity or those prone to forming bubbles. These types of liquids can cause false positives in liquid level detection, so adjusting the algorithm to account for these variables would further reduce the false alarm rate. Additionally, expanding the system's data fusion capabilities could offer greater insights into patient health. By integrating vital signs monitoring modules-such as body temperature, heart rate, and blood pressure-the system could provide a more comprehensive view of a patient's status. This would enable more holistic monitoring, with potential applications in critical care and other specialized healthcare settings.

Enhancing the compatibility and standardization of the system is another important development. Optimizing the Bluetooth protocol to allow seamless integration with existing hospital Information Systems (HIS) or nursing systems would improve the efficiency of data management. Furthermore, the system should be adapted to accommodate different infusion tube specifications (ranging from φ3mm to φ7mm), ensuring that it can be widely applied across various clinical setups.

In terms of hardware, the system can benefit from optimization in power efficiency and compactness. By adopting the Bluetooth Low Energy 5.0 module and employing dynamic sleep strategies, the system could extend its battery life to over 72 hours, making it even more suitable for long-term use in both home and hospital environments. A reduction in the size of the patient's device would also improve patient comfort, making the system less intrusive while maintaining its high level of performance.

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