RESEARCH ON THE DESIGN AND FABRICATION OF INTRAVENOUS FLUID MONITORING DEVICES APPLYING INTERNET OF THINGS TECHNOLOGY

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ABSTRACT

This paper focuses on the research and development of a medical device designed to monitor and supervise intravenous infusion for patients by leveraging Internet of Things (IoT) technologies. The proposed device is expected to have the following fundamental functionalities: setting the volume of the solution to be infused; setting the drip rate in drops per minute; calculating and displaying the remaining volume of the solution; calculating and displaying the remaining infusion time; and Alerting doctors and patients at different time intervals. The advantages of the designed product include low system design cost based on the current price of components; simple and comprehensible programming language with high scalability; experimental results indicating stable and accurate system operation with low power consumption; and ease of operation, use, maintenance, and servicing. Furthermore, the research results have practical applicability in hospitals or medical facilities and can be used as a practice model for Biomedical Engineering students at educational institutions, where there is a significant lack of practical training products in this field.

Keywords: Intravenous infusion; medical devices; monitoring; control; Internet of Things.

1. Introduction

In recent times, traditional methods used to monitor intravenous therapy in healthcare facilities, especially in Vietnam, have become outdated due to the heavy workload and the occasional negligence and lack of attention, which can increasingly harm patient health. Intravenous therapy is an area of research receiving growing interest in modern medicine, with broad potential applications in diagnosing and treating cardiovascular diseases, cancer, and other circulatory system-related conditions. Notably, the development of automated infusion devices utilizing modern communication technologies such as the Internet of Things (IoT) is attracting attention from the scientific research community and manufacturers due to their potential to improve efficiency and meet the increasing demands of clinical practice.

Several surveys on published research and products related to this topic include:

In some recent publications [1]-[3], the authors used Bluetooth technology, which includes various infusion monitoring devices that detect infusion rates and collect data, sending it to a central display at the healthcare station for necessary actions. Another group of authors developed a health information alert system using Bluetooth and GPRS technology, where the system monitors, collects data and sends information to an AI-based analysis counter. Another publication developed a real-time electronic saline monitoring system using infrared sensors to detect drip rates, transmission power, and a servo gauge to control the drip rate mechanism.

In publications from a few years ago [4]-[7], the authors developed an alert system based on Radio Frequency Identification (RFID) technology. This RFID technology functions as a trigger device for the developed system. Specially designed RF tags can be attached to any available fluid package. Another group of authors developed an RFID-based infusion monitoring system using the Zigbee protocol as a sensor, ensuring high accuracy and reliability in monitoring system activity levels.

As in this study, the above surveys indicate that the use of IoT technologies in designing infusion monitoring devices still needs to be improved. Moreover, this research will apply today's most modern and widely used communication technologies. The cost, ease of installation and maintenance, and the ability to customize and update necessary functions are simple. The objective of this paper is to present the design and creation of a device to assist doctors and patients during infusion with the following features:

- Set the volume of the solution to be infused: used to set the volume for the patient, measured in milliliters.
- Set the drip rate (drops/minute): Allows the drops/minute to be set after the doctor has adjusted and counted.
- Calculate and display the remaining solution volume: enables doctors and patients to know the relatively accurate volume of the solution on the LCD screen.
- Calculate and display the remaining infusion time: inform patients and doctors of the remaining time until the infusion is completed.
- Alert doctors and patients when the infusion time is 10 minutes, 5 minutes, and 1 minute remaining.
- The system can communicate wirelessly via Wi-Fi.
- The system can connect to the Internet and provide real-time updates.

2. Research methods and system development

2.1. System block diagram construction

Based on theoretical research on real-world infusion methods from previous studies [2]-[5] and the specific requirements of the problem, the author proposes a technological solution: designing a system to monitor infusion time based on two parameters: the volume of the infusion bottle and the drip rate (drops per minute) to calculate the infusion completion time for the patient. The system employs Wi-Fi communication technology using the ESP8266 Wi-Fi module. Results are simultaneously displayed on an LCD screen and a smartphone app, providing a visual, convenient, and accurate monitoring experience. The block diagram of the system includes the following components (Figure 1):

1. **Infusion bottle volume sensor**: Measures the volume of the infusion solution.
2. **Drip rate sensor**: Detects the number of drops per minute.
3. **Microcontroller unit (MCU)**: Processes sensor data and calculates the remaining infusion time.
4. **ESP8266 Wi-Fi module**: Facilitates wireless communication and data transmission.
5. **LCD display**: Shows the infusion status and remaining time.
6. **Smartphone app**: Receives data from the MCU via Wi-Fi and provides a user-friendly interface for monitoring.

This system architecture ensures real-time monitoring of the infusion process, enhancing accuracy and reliability in clinical settings.

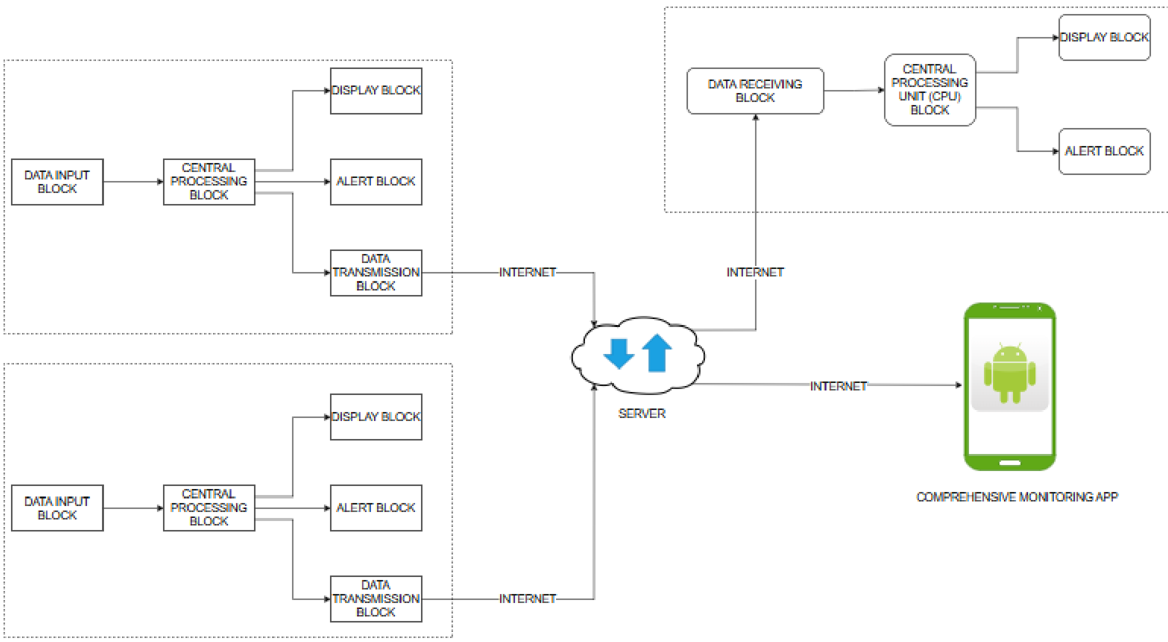


Figure 1: *Block diagram describing the overall system operation*

The functions of each block are described in Table 1:

Table 1: *Components and detailed functions*

Components	Function
Power Supply Block	Provides a 5V power supply for the microcontroller, LCD, LED, and alert speaker.
Microcontroller Unit (MCU) Block	Processes information received from the buttons, calculates the data to be displayed on the LCD and generates alerts through the speaker and LED. Transmits the results via the ESP8266.
Display Block	Displays the volume of the solution to be infused, the infusion rate, the time until infusion completion, and the remaining volume of the solution.
Alert Block	Receives commands from the microcontroller to issue alerts when the infusion time has 10 minutes, 5 minutes, and 1 minute remaining.

Components	Function
Data Input Block	Allows data input for solutions such as volume and infusion rate.
Data Transmission Block	Receives results and transmits them to the Internet, providing real-time updates from the Internet.

Formulating the calculation for infusion time: According to the specifications of standard infusion tubing, 20 drops correspond to 1 ml.

Total time (minutes) = (Total infusion volume in drops/drops per minute)

For example, if the infusion volume is 500 ml, the infusion rate is 100 drops per minute, and standard tubing yields 20 drops per ml, the total infusion time is calculated as:

$$Total\ time = \frac{500x20}{100} = 100\ minutes$$

2.2. Hardware design of the system

a. Circuit design for the system

Based on the survey and the objective of building the product, Figure 2 below illustrates the circuit design principles of the system [6]-[13].

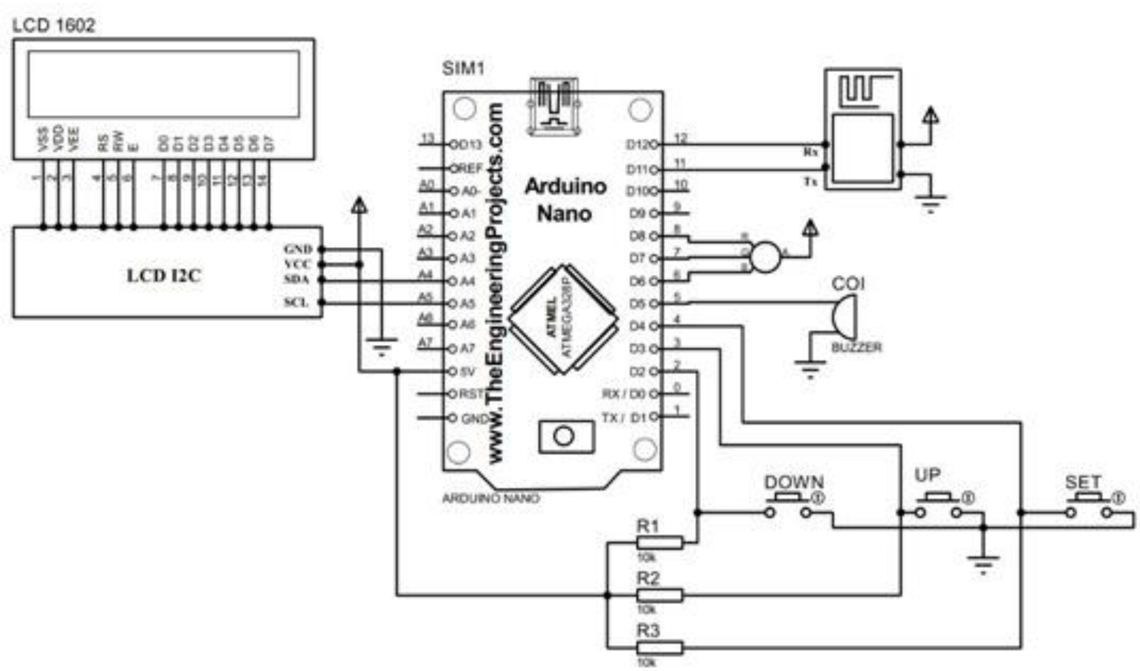


Figure 2: *System principle diagram*

Operating principle:

After powering the system, the ESP8266 will search for and connect to the pre-configured Wi-Fi network. Once the ESP8266 connects to the Internet via Wi-Fi, the LCD screen will display the time. The user can input the infusion volume and rate using the SET, UP, and DOWN buttons and start the infusion timer. The ESP8266 module will transmit the configured data to the smartphone, facilitating monitoring for the physician. As the infusion process nears completion, the device will issue alerts to the physician and the patient. The buttons are connected to Arduino's D12, D11, and D10 pins and are pulled up using internal resistors. When a button is not pressed, the Arduino reads a HIGH logic level; when pressed, it reads a LOW logic level.

The buzzer is connected to the D9 pin of the Arduino. When the Arduino outputs a HIGH logic signal, the buzzer will sound an alert; conversely, when a LOW signal is output, the buzzer will turn off. The RGB LED is connected to the Arduino's D8, D7, and D6 pins. The Arduino outputs a HIGH logic signal to turn the LED on and a LOW signal to turn it off. The ESP8266 module is connected via UART communication, with the Arduino's Tx pin connected to the Rx pin of the ESP8266 and the Arduino's Rx pin connected to the Tx pin of the ESP8266. The ESP8266 operates using power supplied by Arduino. The 16x2 LCD screen is connected to the LCD I2C decoder circuit and communicates with the Arduino via I2C. The SDA pin of the Arduino connects to the SDA pin of the LCD I2C, and the SCL pin of the Arduino connects to the SCL pin of the LCD I2C. The 1602 LCD screen also uses power from the Arduino.

The research tasks include:

● Programming the interface between Arduino and LCD I2C.

● Programming the interface between Arduino and ESP8266.

● Programming input and output communication with buttons, LEDs, and the buzzer.

● Updating real-time information from the Internet and creating a timer.

● Calculating the infusion time.

● Transmitting results to the Internet.

b. Components used in the system

- **Power Supply Block**: The AMS1117-5.0V IC provides power to the Arduino Uno R3 and the LCD.

- **Data Input Block**: Includes buttons that allow the setting of parameters such as the infusion volume and drip rate.

- **Central Processing Unit**: Processes input data from the buttons, calculates, displays on the LCD, and generates alerts.

- **Display Block**: The 16x2 LCD screen shows the infusion volume, drip rate in drops per minute, remaining solution volume, and infusion time.

- **Alert Block**: Includes LEDs and a buzzer to alert the physician and patient when the infusion time has 10 minutes, 5 minutes, and 1 minute remaining.

- **This study utilizes an Arduino Nano** (programmed with the Arduino IDE), a crucial component in the central processing unit that controls the system's operations.

2.3. Software application interface design

a. Algorithm flowchart construction

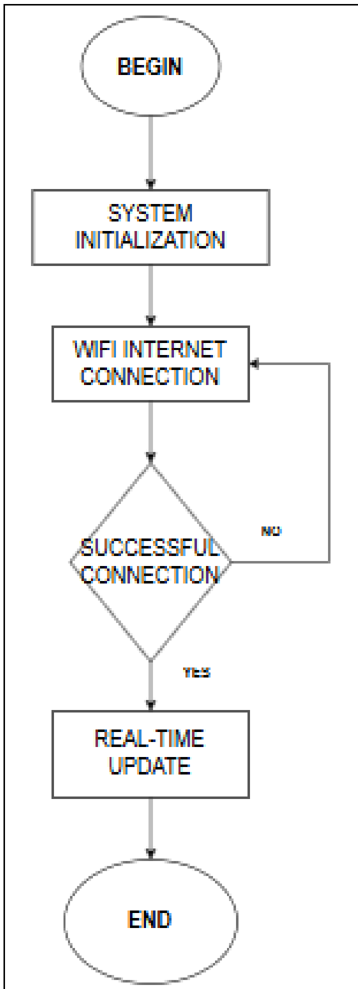
The completed product is a combination of multiple subprograms and programming algorithms. Below are the algorithm flowcharts that sequentially design and program each aspect of the product. Details are illustrated in Figures 3, 4, and 5.

Detailed description of each algorithm flowchart:

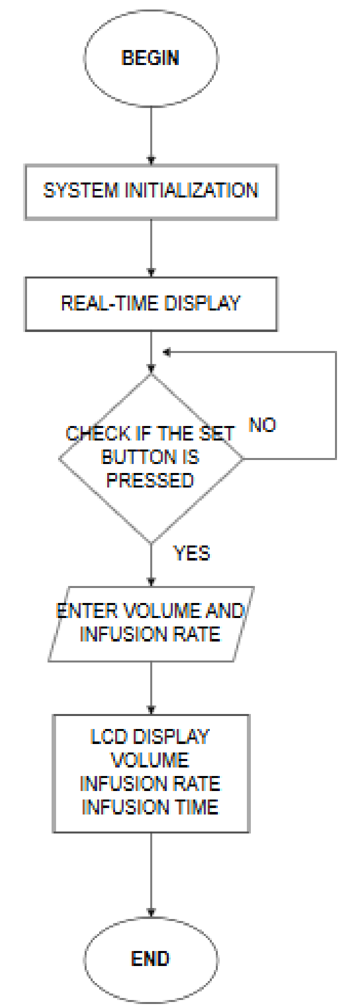
- Connecting to the internet and updating real-time (Figure 3): The ESP8266 module connects to the Internet via Wi-Fi and uses software to obtain the real-time clock from an NTP (Network Time Protocol) server. NTP is a protocol used to synchronize clocks between servers, ensuring that all components in the network are synchronized with Coordinated Universal Time (UTC) to the millisecond. This rapid synchronization makes the real-time clock nearly accurate.

- Program setup algorithm flowchart (Figure 4): After updating the real-time clock, the user inputs two parameters: the infusion volume and the infusion rate. The data entry process is quick and user-friendly. Once the data is entered, the start and end times of the infusion are displayed visually on the LCD.

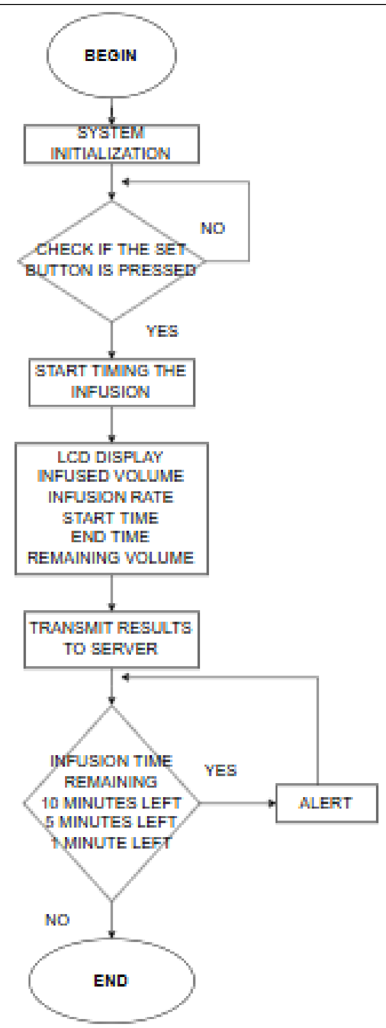
- Infusion monitoring program algorithm flowchart (Figure 5): After setting the volume and rate, the SET button on the device initiates the alert program. The LCD displays the infusion volume and remaining time, which decreases to zero. A `while` loop checks if the remaining infusion time reaches 10 minutes, 5 minutes, or 1 minute, triggering alerts accordingly. When the infusion time ends, the program concludes. Simultaneously, the results are transmitted to the server for real-time updates on the smartphone.



Figures 3: *Connecting to the internet and updating real-time*



Figures 4: *Program setup algorithm flowchart*



Figures 5: *Infusion monitoring program algorithm flowchart*

b. Developing the application software

The application software is developed based on the Blynk platform in this study. Blynk is an iOS and Android application used to control ESP8266, Arduino, Raspberry Pi, and other devices over the Internet. The platform consists of three main components:

● **Blynk App**: Allows users to create interfaces for the product by dragging and dropping various pre-designed widgets provided by the platform.

● **Blynk Server**: Manages the central data processing between smartphones, tablets, and hardware. Users can either use the Blynk Cloud service provided by Blynk or set up their own Blynk server on a personal computer. As an open-source solution, it can be easily integrated into devices and even used with a Raspberry Pi as the server.

● **Blynk Library**: Supports most popular hardware platforms, facilitating communication with the server and handling all incoming and outgoing commands.

3. Results and discussion

Following the research, design, and testing phases, the development and implementation of the medical Infusion monitoring system has been completed. The hardware product includes the following features (Figure 6):

- Volume setting: Allows the required infusion volume to be set.
- Drip rate setting: Enables the configuration of the infusion rate in drops per minute.
- Remaining volume calculation and display: Provides a relatively accurate display of the remaining solution volume on the LCD for the physician and patient.
- Remaining time calculation and display: Shows the time remaining until infusion completion, informing the patient and physician.
- Alerts: Issues warnings to the physician and patient when the infusion time reaches 10 minutes, 5 minutes, and 1 minute.
- Smartphone application: Offers intuitive visual displays for easy monitoring.

Figure 6: *Actual images of the product*

Some images of the product in practical use are shown in Figures 9 to 16:

Figure 7: *Power supply for the device*

Figure 8: *Press the SET button to configure*

Figure 9: *Enter the volume of the infusion bottle*

Figure 10: *Press UP or DOWN to increase or decrease*

Figure 11: *Press SET to continue selecting the infusion rate*

Figure 12: *The Arduino calculates the infusion time*

Figure 13: *Press SET to start monitoring*

Figure 14: *The infusion begins*

Figure 15: *Alert when 10 minutes remain*

Figure 16: *Alert when 1 minute remains*

After the infusion, the device returns to the start screen (Figure 17).

Figure 17: *End of Cycle*

The device continuously monitors the infusion volume and provides immediate alerts to medical staff when abnormalities are detected. The IoT application optimizes patient care processes, minimizes errors, and enhances management efficiency. Clinical trial results show that the device operates stably and accurately, offering promising prospects for widespread application in healthcare facilities.

4. Conclusion

This study has successfully designed and fabricated an intravenous infusion monitoring device utilizing Internet of Things (IoT) technology. The hardware system of the device has achieved essential features, including pre-setting the infusion volume and rate, configuring input parameters, calculating the remaining solution volume, predicting infusion completion time, and providing alerts to physicians and patients through a buzzer and LEDs when the remaining infusion time reaches 10 minutes, 5 minutes, and 1 minute. This device not only supports physicians and patients during intravenous infusions but also contributes to improving effectiveness and safety in medical care. Additionally, the research model and resulting product can serve as practical training equipment for students and trainees in Biomedical Engineering and Electronics Engineering, addressing the current shortage of practical devices for advanced technology applications in healthcare.

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TÓM TẮT

NGHIÊN CỨU THIẾT KẾ, CHẾ TẠO THIẾT BỊ THEO DÕI TRUYỀN DỊCH TĨNH MẠCH ỨNG DỤNG CÔNG NGHỆ MẠNG KẾT NỐI VẠN VẬT

Nguyễn Thị Thu
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Ngày nhận bài 25/6/2024, ngày nhận đăng 23/8/2024

Bài báo này tập trung nghiên cứu và xây dựng một thiết bị y tế có chức năng theo dõi và giám sát việc truyền tĩnh mạch cho bệnh nhân ứng dụng các công nghệ mạng kết nối vạn vật. Sản phẩm được thiết kế dự kiến có các chức năng cơ bản như: Cài đặt thể tích dung dịch cần truyền; Cài đặt số tốc độ truyền giọt/phút; Tính và hiển thị thể tích dung dịch còn lại; Tính và hiển thị thời gian truyền còn lại; Cảnh báo cho bác sĩ, bệnh nhân ở các mốc thời gian khác nhau. Ưu điểm của sản phẩm thiết kế bao gồm: chi phí thiết kế hệ thống thấp theo giá thành mua sắm linh kiện vào thời điểm hiện tại; ngôn ngữ lập trình đơn giản dễ hiểu và có khả năng mở rộng cao; kết quả thực nghiệm cho thấy hệ thống hoạt động ổn định chính xác với điện năng tiêu thụ ít; Hệ thống dễ vận hành sử dụng và bảo trì bảo dưỡng. Hơn nữa, kết quả của nghiên cứu có tính thực tiễn trên thực tế tại các bệnh viện hoặc cơ sở y tế, có thể sử dụng làm mô hình thực hành cho sinh viên ngành Kỹ thuật Y sinh tại các cơ sở đào tạo, nơi còn đang rất thiếu nhiều các sản phẩm thực hành về lĩnh vực này.

Từ khóa: Tĩnh mạch; thiết bị y tế; giám sát; điều khiển; mạng kết nối vạn vật.