Applied Engineering, Innovation, and Technology

Research article

Design and Implementation of an IoT-Based Intravenous Infusion Monitoring System Using Wireless Sensor Network

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https://doi.org/10.62777/aeit.v1i2.25

Received: 14 August 2024
Revised: 31 August 2024
Accepted: 4 September 2024
Published: 6 October 2024

Abstract: This research presents a Wireless Sensor Network (WSN) based infusion monitoring system that utilizes Internet of Things (IoT) technology to enhance infusion management in healthcare. Manual supervision often lacks the necessary accuracy and control, making automated solutions crucial. Our system employs optocoupler and load cell sensors to calculate the infusion drop rate per minute and assess the remaining fluid percentage. Tests conducted demonstrated that optocoupler sensors effectively measured the drop rate, while load cell sensors accurately determined fluid levels. Measurement results are easily monitored via smartphone, granting healthcare professionals rapid access to vital data. A key innovation of this system is its ability to enable remote monitoring through WSN, allowing a single nurse to oversee multiple infusions with just one smartphone. The test results indicate impressive accuracy, achieving an average precision rate of 97% for drop rate measurements and 93% for remaining fluid percentage measurements. Overall, this system offers an efficient and controlled approach to infusion fluid management, ensuring optimal care for patients. By integrating IoT and WSN technologies, this research lays the groundwork for developing more advanced and interconnected infusion monitoring systems, ultimately enhancing patient care in today's globalized healthcare environment.

Keywords: healthcare, Internet-of-Things, intravenous infusion, optocoupler, smartphone, wireless sensor network

1. Introduction

In healthcare, globalization plays a vital role in driving scientific advancement and innovation. The ongoing development of medical technology, particularly through the Internet of Things (IoT), significantly enhances the efficiency and accuracy of medical services [1]. However, many healthcare settings still face challenges that necessitate technological improvements to foster innovation. Medical professionals are expected to leverage these advancements to elevate the quality of health services for their communities [2]. Consequently, the field of Electronics and Instrumentation has emerged as a critical focus for the new generation of technology designers [3].

One persistent challenge in healthcare is the manual administration of intravenous infusions, which can lead to complications such as blockages or interruptions in fluid flow. In some cases, medical staff may not be aware of issues like blood entering the infusion line due to depleted fluid, potentially resulting in patient dehydration or fluid deficiency [4]. Intravenous infusion is essential for replenishing lost fluids and nutrients, and its effective administration is crucial for patient recovery [5], [6].

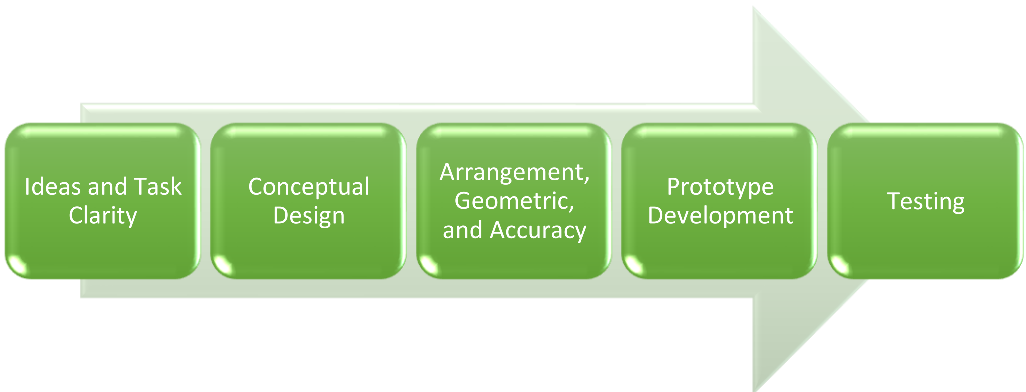
In Indonesia, healthcare services are predominantly concentrated in the western regions, which can hinder equitable access to quality care across the country [7]. Previous research has developed an IoT-based infusion monitoring device with smartphone integration, allowing remote monitoring of infusion status [8]. However, this system is limited to monitoring a single patient per smartphone, posing challenges in busy healthcare settings where patient numbers may exceed available nursing staff. To address this limitation, this research introduces an innovative system utilizing a Wireless Sensor Network (WSN) that enables one nurse to manage multiple patient infusions using a single smartphone. This advancement is particularly beneficial during patient surges, enhancing healthcare service delivery [9]. Our system employs an optocoupler sensor to count infusion drips per minute, measuring the duration an object obstructs light from the sensor [10]. Additionally, it evaluates the remaining fluid percentage, providing critical information for effective patient care.

The IoT facilitates seamless data exchange among connected devices, allowing for autonomous data transmission that increases efficiency in medical services [11], [12]. By integrating IoT technology and WSN, this research aims to revolutionize infusion monitoring systems, significantly reducing human error and improving patient safety. The proposed system has the potential to enhance data accessibility for healthcare professionals, ultimately advancing the quality of patient care and paving the way for future innovations in connected healthcare solutions [13], [14], [15].

2. Methods

This research employs an engineering approach, integrating scientific principles into the design process to achieve specific objectives. The phases of this research are illustrated in Figure 1, which outlines the stages of engineering research that incorporate innovative elements [14]. These stages include ideation, conceptual design, geometric and functional arrangement, detailed design, prototype development, and testing.

Figure 1. Research phases.



The focus of this study is the design of a wireless sensor network-based infusion monitoring system with a smartphone display. The tools and materials utilized consist of a personal computer (PC) for programming in Arduino IDE, which is subsequently uploaded to the Node MCU, along with various electronic components such as optocouplers, load cells, and servo motors.

The infusion fluid monitoring system is developed with a strong emphasis on both hardware and software components. Software design is critical, providing the necessary instructions for hardware operation, while hardware encompasses the physical elements used in monitoring the infusion fluid. Figure 2 illustrates the detailed hardware components of the system. A key objective in this phase is to ensure seamless integration between the hardware and software to achieve accurate and reliable monitoring.

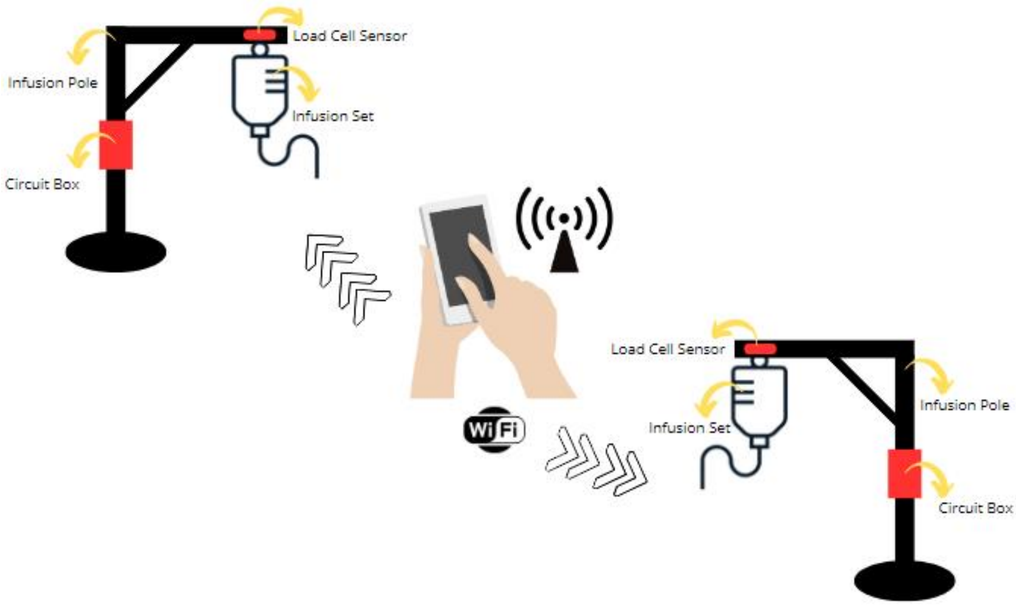


Figure 2. Conceptual design of the infusion monitoring system based on WSN.

As shown in Figure 2, the circuit box houses the Node ESP32, which is connected to a load cell, optocoupler, and servo motor. The optocoupler sensor, installed on the infusion tube, detects drops, enabling calculation of the infusion rate. The servo motor is also attached to the infusion tube, while the infusion bottle is suspended on the load cell, which measures the remaining fluid level.

To facilitate the operation of the designed hardware, sensors are programmed using the Arduino programming language within the Arduino IDE. The system connects to an available Wi-Fi network, allowing data to be transmitted to the cloud platform, ThingSpeak. Concurrently, the App Inventor application is developed to display monitoring data, such as the number of drops per minute and the remaining fluid level, on a smartphone screen. The software design process using App Inventor is detailed in Figure 3.

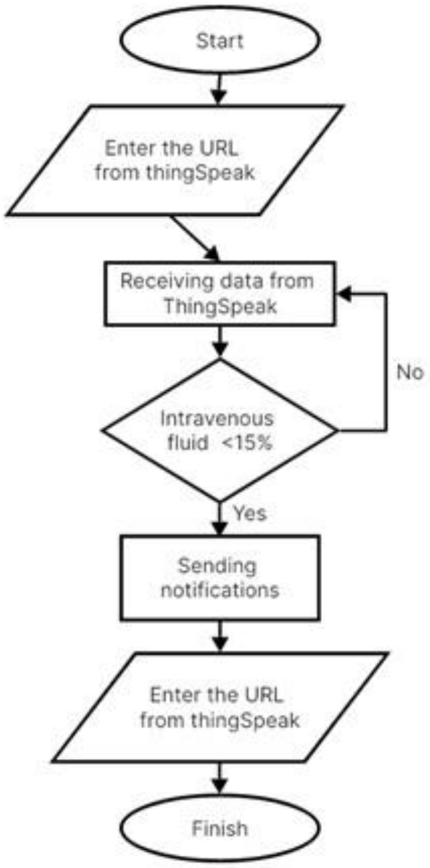


Figure 3. Software design flowchart.

Figure 3 illustrates the flow of the App Inventor software. The process begins with entering the ThingSpeak URL as the initial step. Subsequently, the data stored in ThingSpeak is defined within the App Inventor environment, allowing the application to accurately display information, such as the remaining fluid percentage and the infusion drop count, to the user.

3. Results and Discussion

The outcome of this research is a wireless sensor network-based infusion monitoring system, which features a user-friendly interface accessible via smartphone. This device accurately calculates both the remaining infusion fluid and the infusion drop rate per minute, displaying real-time monitoring data directly on the user's smartphone screen. The mechanical design of the system, showcased in Figure 4, utilizes advanced electronics and sensors for precise calculations. The core components of the system include a load cell sensor and an optocoupler, which are essential for its accurate operation.

Figure 4. Infusion fluid monitoring system with WSN.

The ESP32 Node MCU serves as the central processing unit of the system (see Figure 5), facilitating data processing and connection to smart devices, particularly smartphones. This integration of components—including the servo motor, optocoupler, and load cell sensor—ensures smooth operation and efficient synergy. Figure 5 illustrates how the ESP32 microcontroller interfaces with various sensors and motors to optimize infusion monitoring.

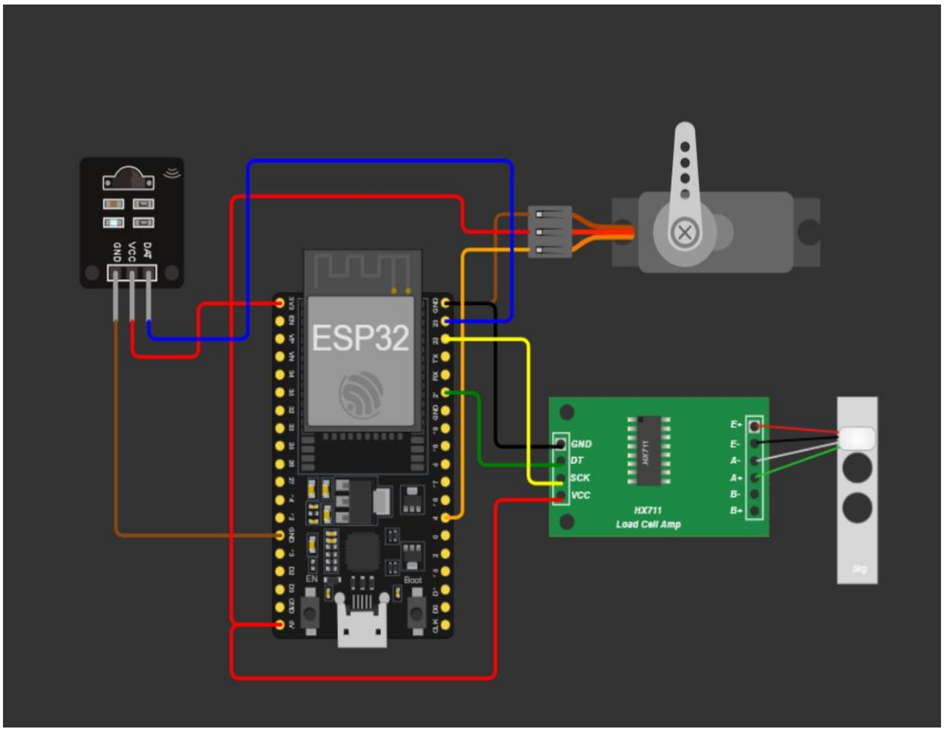


Figure 5. ESP32 microcontroller with various sensors and components.

Furthermore, figure 6 presents the smartphone user interface, highlighting its control functions for servo motor adjustments and drip rate settings. The interface also provides real-time updates on the remaining infusion fluid percentage, calculated through the load cell sensor. An automatic notification alerts the user when the remaining fluid drops below 15%, prompting timely replacement.

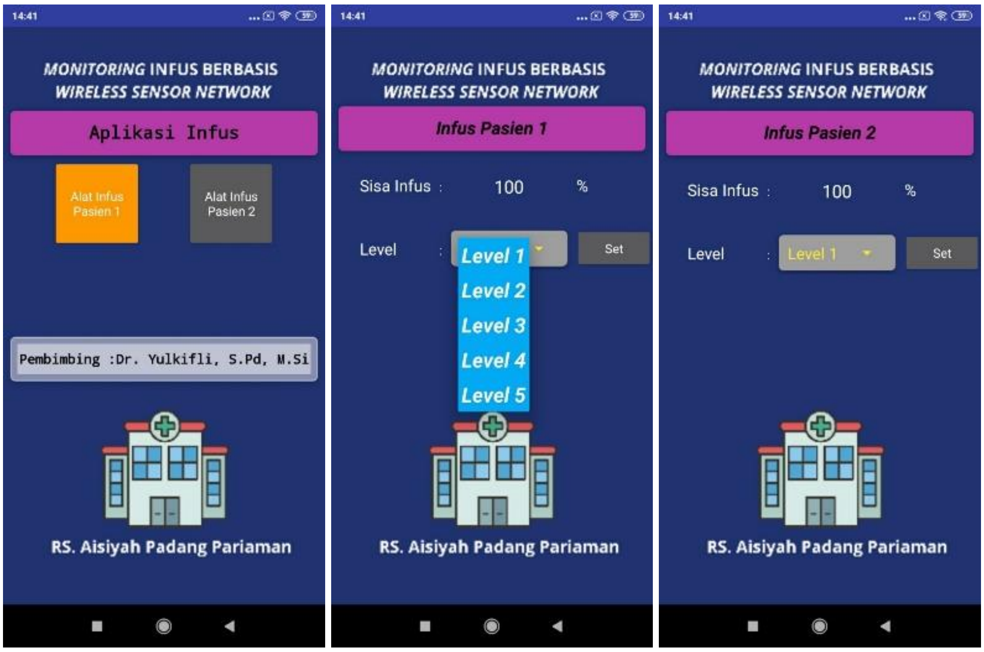


Figure 5. Infusion monitoring interface with WSN on smartphone.

To evaluate the system's accuracy in measuring remaining fluid and drop rates, tests were conducted, and results are summarized in Tables 1 and 2. For instance, at a mass of 500 grams, the system achieved a 0% error rate, demonstrating perfect accuracy. However, deviations were noted with smaller masses, such as a 15% error at 100 grams. These discrepancies, while minor, warrant further investigation to identify potential causes, especially at lower masses.

Table 1. System's accuracy on infusion in patient 1.

Mass (gr)	Measured	Calculated	Error (%)	Accuracy (%)
500	100	100	0	100
450	91	90	1	99
400	81	80	1	99
350	71	70	1	99
300	62	60	3	97
250	52	50	4	96
200	43	40	8	93
150	32	30	7	93
100	23	20	15	85
50	11	10	10	90
	Average		**5**	**95**

Table 2. System's accuracy on infusion in patient 2.

Mass (gr)	Measured	Calculated	Error (%)	Accuracy (%)
500	100	100	0	100
450	90	90	0	100
400	81	80	1	99
350	73	70	4	96
300	62	60	3	97
250	52	50	4	96
200	41	40	4	98
150	33	30	10	90
100	23	20	15	85
50	13	10	30	70
	Average		**5**	**93**

The data in Table 1 indicates a generally high level of accuracy, with most measurements closely aligning with expected values. However, variations in precision were observed, with the average precision at 95% and occasional lower results, such as 93% at 200 grams. This suggests fluctuations in measurement consistency, likely influenced by operational conditions. Identifying these factors is crucial for enhancing measurement accuracy and reliability. Similarly, Table 2 shows an average difference between measured and expected values of only 1-4%, with notable larger variations at specific masses (e.g., 150 grams and 50 grams). An outlier was identified at 50 grams, where the error reached 30%, indicating the need for further investigation into the causes of these discrepancies.

Overall, both analyses demonstrate a high level of precision. However, the first analysis displayed more consistent results, while the second exhibited slight variations, particularly with the 50-gram measurement. Despite these differences, both datasets maintain an average error rate of 5%, demonstrating reliability in measuring drop rates and remaining fluid percentages.

The accuracy testing results for the drop rate measurements from the optocoupler sensors are presented in Tables 3 and 4. Data 3 achieved an average accuracy of 97%, with minimal variations (5-9%) primarily attributed to calibration or environmental factors. Data 4 performed slightly better, achieving an average accuracy of 98%, underscoring its suitability for clinical applications where precision is paramount. The enhanced accuracy in Data 4 makes it preferable for managing sensitive infusion processes. Nevertheless, Data 3 remains reliable, with only minor discrepancies. Both datasets provide consistent results, but further exploration of the factors causing variations will help refine the system. This comparative analysis highlights that the current infusion monitoring system offers significant improvements over previous technologies, delivering higher accuracy, reliability, and a user-friendly interface. Such advancements will positively impact medical practice by providing a dependable tool for infusion monitoring, ultimately optimizing patient care.

Table 3. System's accuracy on drop rate measurement in patient 1.

Set point input	Measured	Error (%)	Accuracy (%)
20	20	0	100
20	20	0	100
20	21	5	95
20	22	9	90
20	20	0	100
20	19	5	95
20	21	5	95
20	19	5	95
20	20	0	100
20	20	0	100
Average		**3**	**97**

Table 4. System's accuracy on drop rate measurement in patient 2.

Set point input	Measured	Error (%)	Accuracy (%)
20	20	0	100
20	19	5	95
20	20	0	100
20	21	5	95
20	20	0	100
20	19	5	95
20	21	5	95
20	19	5	95
20	20	0	100
20	20	0	100
Average		**2**	**98**

4. Conclusions

The research findings demonstrate that the infusion fluid monitoring system utilizing Wireless Sensor Network (WSN) technology achieves impressive precision, with an average drop count accuracy of 97-98% and fluid measurement accuracy of 91-93%, resulting in a relative error of only 3-9%. This system effectively monitors infusion drop rates and remaining fluid percentages while providing real-time, remote access via smartphone. It successfully addresses critical gaps identified in the literature, particularly the need for enhanced precision and real-time monitoring capabilities in existing systems.

Future research should focus on several key areas to further advance this technology. First, improving sensor calibration techniques is essential to enhance accuracy and consistency. Additionally, efforts should be directed toward minimizing measurement variations caused by environmental factors and sensor drift. Integrating the system with other medical devices and health records could facilitate more comprehensive patient monitoring. Furthermore, developing scalable solutions that adapt to various clinical settings and different infusion types will broaden the system's applicability. Enhancing the smartphone interface for improved usability and incorporating predictive analytics for infusion needs could significantly boost the system's effectiveness. These recommendations aim to refine performance and expand the utility of the infusion monitoring system in clinical environments, ultimately improving patient care.

Funding: This research received no external funding.

Data Availability Statement: Due to privacy restrictions, the data of this study is unavailable.

Conflicts of Interest: The authors declare no conflicts of interest.

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