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Optimization of an Internet of Things–Based Infusion Monitoring and Control System (OSPKI-IoT)

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ABSTRACT

Nurses have an important role in patient care in hospitals, but excessive workload can cause errors in monitoring IV fluids. This research aims to develop an Internet of Things (IoT) based infusion monitoring and control system to increase efficiency and accuracy in managing infusion fluids. The system developed is capable of monitoring the volume of infusion fluid, counting drops per minute, and controlling the infusion speed automatically, as well as connecting to a database for online monitoring. The research method uses an experimental method with Waterfall model-based system development, which includes the stages of requirements analysis, system design, implementation, testing, and maintenance.. Test results show that the system can work accurately in monitoring various types of infusion fluids with a low error rate. It is hoped that the development of this system can reduce the risk of infusion monitoring errors and improve patient safety in hospitals. The novelty of this study lies in the integration of IoT-based infusion drip speed control automation in real time via a website with sensor accuracy below 1%, which has not been widely implemented in similar studies in Indonesian clinical settings.

1. Introduction

Nurses play a vital role in delivering healthcare services in hospitals. They are responsible for ensuring patient safety, monitoring patients' health conditions [1–8], and providing assistance and information related to medical care. However, heavy workloads often make it difficult for nurses to maintain optimal service quality [4][18]. This condition increases the likelihood of errors in performing tasks, including monitoring intravenous (IV) fluids, which can ultimately affect patient safety and the overall quality of healthcare services.

Excessive workload is one of the main factors contributing to a higher risk of errors in nursing services, particularly in the supervision of IV fluids. In Indonesia, the reporting rate of patient safety incidents remains low, with only 12% of hospitals reporting such events in 2019. Moreover, mortality associated with medical incidents is relatively high, reaching 2–16 cases per 100 patients [4]. These figures indicate an urgent need to strengthen patient safety culture and improve service quality in hospitals.

Infusion therapy is a common medical procedure used to deliver fluids, electrolytes, or medications directly into the bloodstream. Manual installation and monitoring of IV infusions pose risks such as under-infusion or fluid imbalance. Errors in infusion regulation may lead to severe complications for patients [2]. Therefore, an automated system capable of monitoring and adjusting infusion flow rates in real time is needed to enhance patient safety and improve the efficiency of medical staff [10].

To address these issues, an Internet of Things (IoT)-based infusion monitoring device was developed [11]. This device measures fluid volume, calculates drops per minute, and controls flow rate using a servo mechanism. The collected data are stored in a database and made accessible through a web interface. This system enables easier, more accurate, and more

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efficient monitoring of IV fluids, helping nurses reduce the risk of under-infusion and improving patient safety [5][15][12].

Based on this background, the study aims to address three central problems: minimizing medical staff negligence in IV fluid control through an IoT-based system; evaluating the accuracy of sensor data transmission to the website; and determining whether the system can function optimally with different types of infusion fluids. The scope of the study focuses on the system's ability to accurately receive sensor data over a local network, using two infusion types—Ringer's lactate and sodium chloride [6]. Unlike previous studies [5][12][15], this research not only monitors but also optimizes infusion drip control automatically based on real-time sensor data transmitted to the website. This approach is expected to enhance medical staff efficiency and monitoring accuracy.

The main objective of this research is to assist nurses in efficiently monitoring patients' IV fluids via a web-based platform. Additionally, it aims to develop an accurate remote monitoring system, provide predictions on infusion depletion time to support timely replacement, and evaluate system performance across different fluid types. With this system, nurses are expected to perform timely interventions, thereby improving patient safety and care quality.

2. Research methods

This research was conducted at Klinik Cobogo Medika, located at Jl. Raya Serang Cibarusah No. 19, Bekasi Regency, West Java. The study focuses on the development of an Internet of Things (IoT) based infusion monitoring and control system, including an analysis of how the system is designed, tested, and maintained to achieve the intended objectives [2][5][7]. Data collection was carried out using two primary techniques: direct observation and interviews [2][5]. Observation was used to examine the implementation of the system within the clinical environment, while interviews with medical personnel and relevant stakeholders provided in-depth insights into their experiences with infusion fluid management [4][18]. Through this approach, the study aims to gain a clearer understanding of the effectiveness of the proposed system [13].

The object of this research is the IoT-based infusion monitoring and control system, which was developed using the waterfall methodology. This method consists of several structured stages, including requirements analysis, system design, implementation, testing, and maintenance [3]. The requirements analysis stage involved evaluating the necessary system functionalities and performance specifications [11]. The design phase covered both hardware and software planning [8][9], followed by implementation and testing to ensure that each system component operated properly [6][8]. Comprehensive testing was conducted to verify data accuracy and system efficiency within the clinical environment [2][13][15].

The research workflow was structured to ensure success at each stage. It began with data collection, followed by an analysis of functional and non-functional requirements, and continued with system planning for both hardware and software components [7][13]. System testing was performed to confirm that all components including sensors, servers, and the web interface functioned reliably and delivered results consistent with operational needs. The findings of this study will serve as the basis for recommendations regarding further development of the IoT-based infusion monitoring and control system [7][9], with the expectation of improving efficiency and accuracy in infusion fluid management within clinical settings.

3. Results and Discussion

3.1 Result

Based on the block diagram and component design described earlier, this study produced an optimized Internet of Things (IoT)–based infusion monitoring and control system. The system functions to monitor and regulate the drip rate and fluid volume of infusion bags in patient rooms using an ESP8266 module. The implementation of the device on the infusion bag is shown in Figure 1, which illustrates the drip and volume monitoring mechanism. Meanwhile, the monitoring dashboard display is presented in Figure 2.

Figure 1 Infusion Drip and Volume Monitoring Device

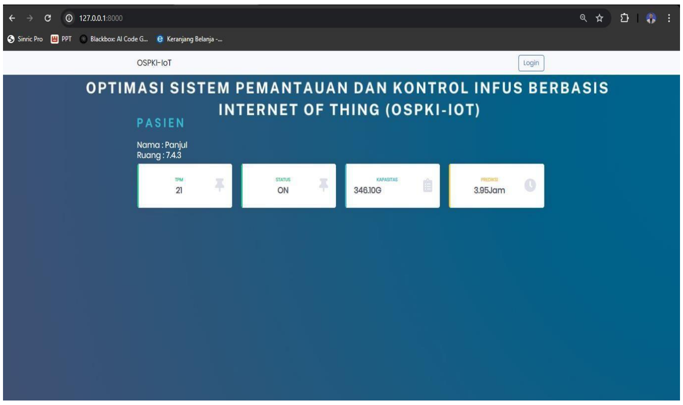

Figure 2 Dashboard Monitoring

3.1.1 Result for test Hardware

The results of the correlation and load cell sensor testing are divided into several parts, namely:

a. Result for tet Sensor Speed Count

The Speed Count sensor was tested five times with the objective of achieving 63 drops per minute (TPM), using a formula to calculate the percentage error. The results of these tests are documented in Table 1, which records the accuracy evaluation of the sensor readings, and in Figure 40, which presents the corresponding evaluation graph.

Table 1
Test ofr erorr reading sensor

Test Number-	Target TPM	Reading Sensor	Eror (%)
1	63	63.8	1.3
2	63	63.2	0.3
3	63	63.4	0.6
4	63	63.2	0.3
5	63	63.2	0.3
Average Error			0.56

b. Result for test sensor load cell

The load cell sensor test results were obtained through three stages: the first calibration error test, the second calibration error test using Ringer Lactate solution, and the third calibration test using Sodium Chloride solution. The error results from the initial sensor calibration, which used a set factor of –216225 and was calibrated with a total infusion bag weight of 565 grams, will be presented in Table 2 as the results of the first calibration error test.

Table 2.
Tets for erorr first calibration

Test Number -	Conventional Scales	Set Factor	Berat Load Cell	Erorr (%)
1	556 g	-216225	55g	0.17
2	260 g	-216225	26g	0.38
3	215 g	-216225	216g	0.46
4	115 g	-216225	116 g	0.86
5	100 g	-216225	101 g	1
Average Erorr (%)				0.57

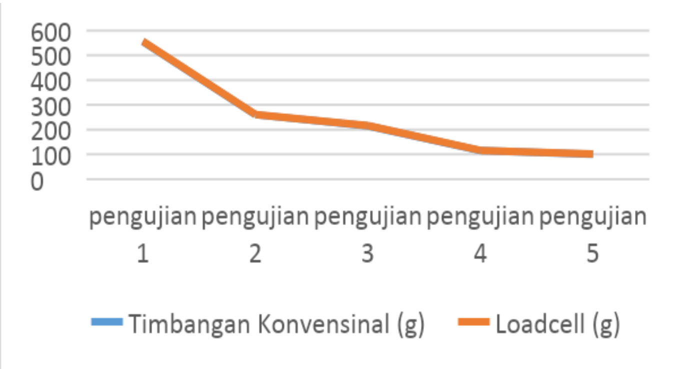

Figure 3 Test for the first calibration

The graph of this test can be seen in Figure 3, which presents the calibration error evaluation using a percentage error formula. This calibration test, conducted using a set factor of –238025, focused on the Ringer Lactate solution with a weight of 505 grams. A comparison with a conventional scale for this fluid composition indicates that the infusion bag packaging weighs approximately 60 grams. The results of this calibration error test will be presented in Table 3, which documents the second calibration error evaluation for the Ringer Lactate solution, as well as in Figure 4, which displays the calibration error graph using the percentage error formula.

Table 3
Test for error Ringer's *Lactate*

Test Numbe r	Convention al Scales	Set Factor	Berat Load Cell	Erorr (%)	Test Num ber -
1	556 g	505 g	-238025	505 g	0
2	260 g	209 g	-238025	210 g	0.4
3	215 g	164 g	-238025	165 g	0.6
4	115 g	64 g	-238025	64 g	0
5	100 g	49 g	-238025	50 g	2
		Average Erorr (%)			0.6

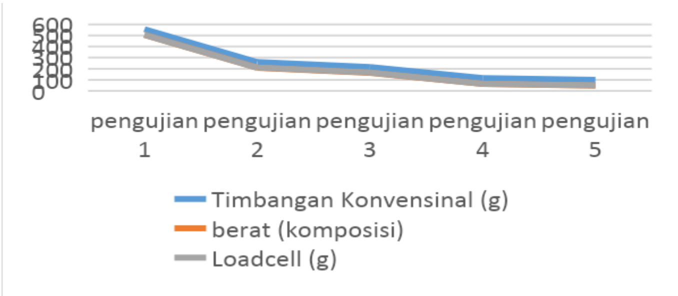

Figure 4 Graph for test error Ringer Lactate liquid

The third stage of sensor calibration error testing was conducted using a Sodium Chloride solution with a set factor of –238025. The results of this calibration error test will be presented in Table 4, which displays the third calibration error evaluation using Sodium Chloride solution, and in Figure 5, which illustrates the corresponding error graph calculated using the percentage error formula.

Table 4.
Test for error Cairan Sodium Chloride

Test Number -	Conventional Scales	Set Factor	Berat Load Cell	Erorr (%)	Test Number -
1	555 g	504 g	-238025	507g	0.3
2	256 g	205 g	-238025	207g	0.9
3	201 g	150 g	-238025	151g	0.6
4	106 g	55 g	-238025	57g	3.6
5	91 g	40 g	-238025	41g	2.5
	AVERAGE EROR (%)				1.58

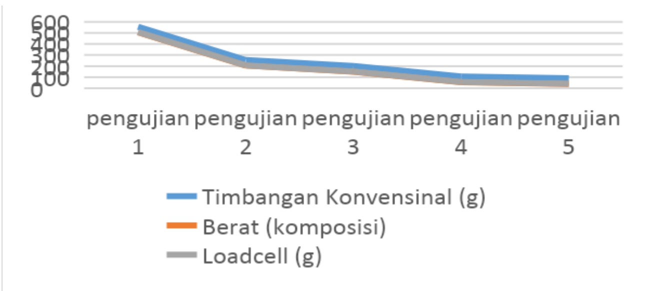

Figure 5. Graph test error Cairan Sodium Chloride

In addition, the one-hour device testing using the set factor –238025 showed an error rate of 0.6% for the Ringer Lactate solution and 1.58% for the Sodium Chloride solution, as obtained from the sensor calibration process. These test results are presented in two parts: Figure 6, which displays the graph of the TPM and capacity testing for Sodium Chloride, and Figure 7, which presents the graph of the testing results for Ringer Lactate.

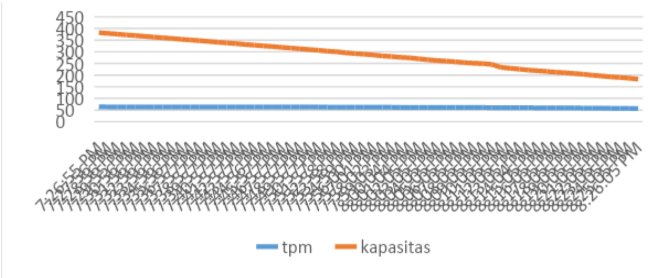

Figure 6. Graph Test TPM and weighted Sodium Chloride

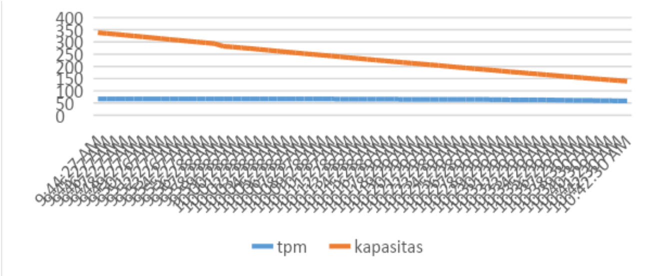

Figure 7. Graph Test TPM and capacity Ringer Lactate

Based on the analysis of the figures above, the graphs of TPM and infusion capacity exhibit the expected pattern, namely a gradual decrease in fluid volume corresponding to the patient's fluid needs [2][5]. The TPM values also show a slow decline over time, primarily due to reduced air pressure within the infusion bag and potential disturbances in the infusion needle, such as movement or partial blockage. The observed stability in TPM data may be attributed to the smooth flow conditions of the infusion set used, as well as the sufficient fluid volume and air space within the infusion bag, which prevent significant fluctuations.

c. Result for Test OLED 128x64

The OLED testing results were obtained from three cycles of turning the device off and on. The results of this OLED test will be presented in Table 5.

Table 5.
Result Test OLED

Test for-	Desciption
1	Succes
2	Succes
3	Succes

success rate = n3x100%= 33x100%=100%

d. Result for testing Button

The button testing results were obtained from three button-press trials. The results of this button test will be presented in Table 6.

Table 6.
Result for Testing button

Testing-	Description
1	Succes
2	Succes
3	Succes

success rate = n3x100%= 33x100%=100%

3.1.2 Result for testing connectivity NodeMCU and Website

a. Result for testing NodeMCU ESP8266 to Database

The results of the data transmission test from the NodeMCU ESP8266 to the database [14] were obtained from four data-sending trials. These results will be presented in Table 14, which shows the outcomes of the NodeMCU ESP8266 data transmission to the website database, as well as in Figure 8, which illustrates the results of this test.

Table 14.
Result testing sending data NodeMCU ESP8266 to database website

Testing for	Description
1	Succes
2	Succes
3	Succes
4	Succes

Persentase Success = n4x100%= 44x100%=100%

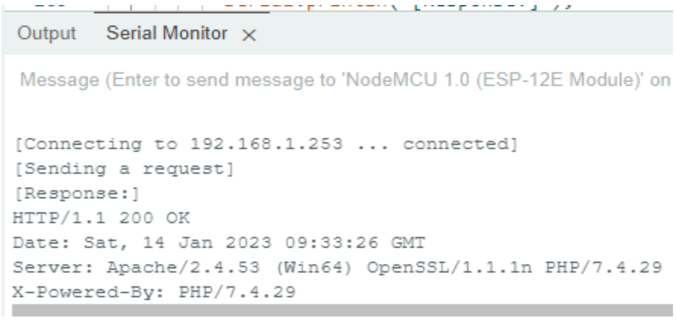

Figure 8 Result for sending data NodeMCU ESP8266 to database website

b. Result testing user interface data to website

The results of the website data display test were obtained from three website refresh trials. The test results will be presented in Table 15, which shows the performance of the data display on the website, and in Figure 9, which illustrates the website data display output.

Table 15.
Result for testing interface data to website

Testing-	Description
1	Succes
2	Succesl
3	Succes

Persentase Succes= n3x100%= 33x100%=100%

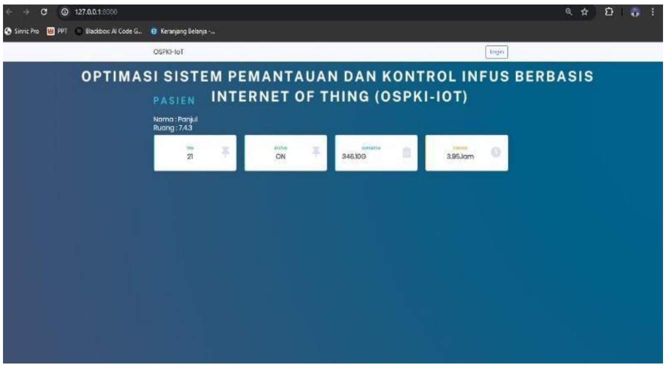

Figure 9 Result interface data to website

c. Result for testing adding tools to the database

The results of the device addition test to the database were obtained from three trials of entering the device code. These results will be presented in Table 16, which shows the outcomes of adding the device to the website. Figure 10 illustrates the device addition process in the database, and Figure 11 displays the data successfully added to the device list.

Table 16.
Result testing add tools to the website

Testing for-	Description
1	Succes
2	Succes
3	Succes

Persentase succes = n3x100%= 33x100%=100%

	id	status	created_at	updated_at
Edit Copy Delete	11111111	Berhasil Ditambah	2024-06-08 16:24:32	2024-06-08 16:24:32
Edit Copy Delete	22222222	Berhasil Ditambah	2024-06-24 08:02:49	2024-06-24 08:02:49
Edit Copy Delete	33333333	Berhasil Ditambah	2024-06-24 08:02:57	2024-06-24 08:02:57

Figure 10 Result add tools to database

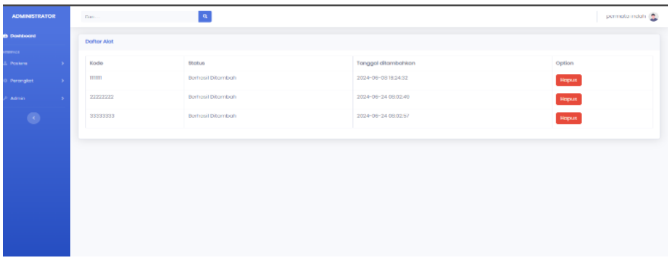

Figure 11 Result add tools to database

d. Result testing add patient and velocity infus

The results of the patient addition test on the website were obtained from three trials of entering patient data. These results will be presented in Table 17, which shows the outcomes of updating patient data on the website. Figure 12 illustrates the process of adding a patient to the database, Figure 13 shows the results of editing patient data on the website, and Figure 14 demonstrates the servo operating normally.

Table 17.
Result testing add patient and velocity infus

Testing for	Description
1	Succes
2	Succes
3	Succes

Persentase succes = n3x100%= 33x100%=100%

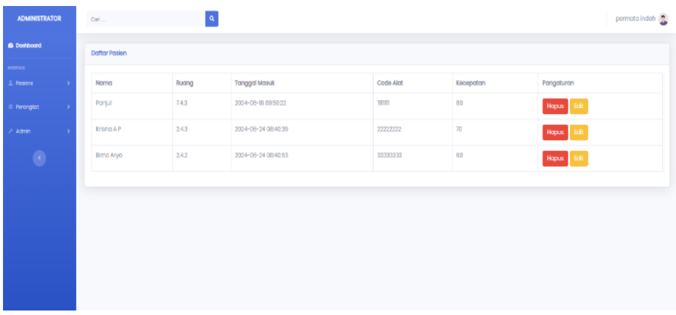

Figure 12 Result add patient and velocity unfu to webite

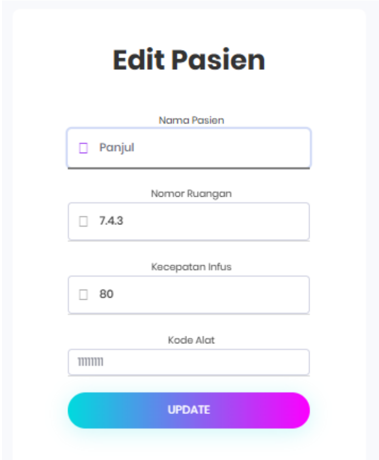

Figure 13 Result edit patient andpPateint drops to website

Figure 14 Servo running normaly

e. Result Testing Login

The results of the website login test were obtained from three login attempts. These results will be presented in Table 18, which shows the outcomes of the website login test, and in Figure 15, which displays the login results on the website.

Table 18.
Result of login testing to dashboard admin

Testing for	Description
1	Succes
2	Succes
3	Succes

Persentase succes = n3x100%= 33x100%=100%

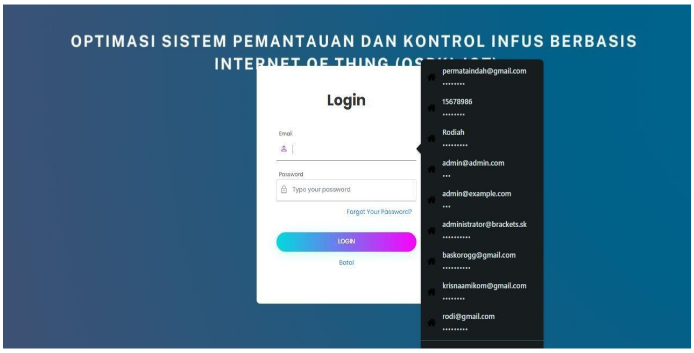

Figure 15 Result testing login admin

f. Result Testing List Tools and Remove Tools

The results of the device registration and deletion tests on the website were obtained from three trials of adding and removing a device. These results will be presented in Table 19, which shows the outcomes of the device deletion test on the website. Figure 16 displays the data before deletion, and Figure 17 shows the results of the device listing and deletion processes on the website. The deleted data correspond to the device code 33333333.

Table 19.
Result testing tools list and remove list from the website

Testing for	Description
1	Succes
2	Succes
3	Succes

Persentase succes = n3x100%= 33x100%=100%

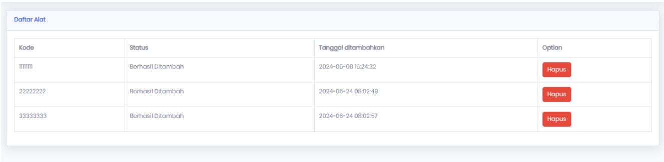

Figure 16 Data tools removed before

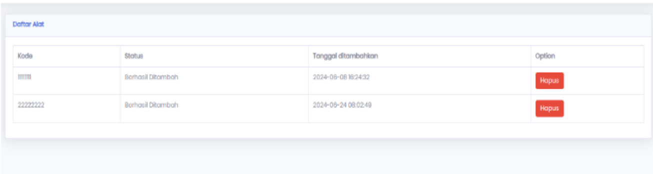

Figure 17 Result list of tools and removed tools from website

g. Result Testing Add Admin

The results of the website data display test were obtained from three trials of registering a new admin. These results will be presented in Table 20, which shows the outcomes of adding an admin to the website. Figure 18 illustrates the admin input form, while Figure 19 shows the successful data addition notification as well as the final result of adding the admin to the website.

Table 20. Result testing add admin to website

Testing for	Description
1	Succes
2	Succes
3	Succes

Persentase succes = n3x100%= 33x100%=100%

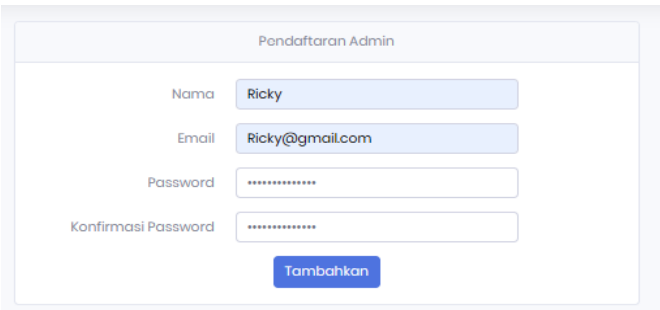

Figure 18 Add admin input

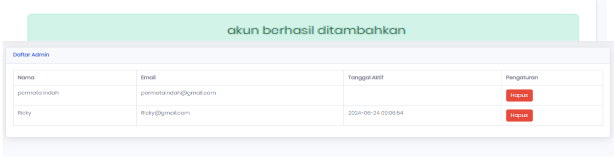

Figure 19. Result add to website

h. Result Testing Warning Website

The results of the website data display test were obtained from two monitoring trials using two different infusion fluids over a period of one hour. These results will be presented in Table 21, which contains the outcomes of the website alert testing.

Table 21.
Result testing warning in website

Nuber testing	Status	Description
1	HIGH	Succes
	LOW	Succes
	HIGH	Succes
2	LOW	Succes

3.2 Discussion

Based on the series of tests conducted, the system demonstrates excellent performance across all components. The input evaluation shows that the Correlation Photoelectric Speed Count sensor is capable of detecting infusion fluid droplets with high accuracy. Additionally, the load cell sensor, calibrated using the NodeMCU ESP8266, is able to measure the infusion fluid weight precisely. The Drops Per Minute (DPM/TPM) values processed by the NodeMCU ESP8266 can also be reset using a push button and are clearly displayed on the 128×64 OLED screen.

The performance of the Correlation Photoelectric Speed Count sensor has been validated using the commonly applied TPM formula in medical applications, confirming that the program running on the NodeMCU ESP8266 operates according to expected standards. A one-hour monitoring test further indicates that the sensor is capable of maintaining stable and consistent readings. Although the TPM value decreases over time due to reduced air pressure in the infusion bag and potential obstruction in the infusion needle, the sensor continues to deliver reliable and accurate data. The TPM and weight data processed by the NodeMCU ESP8266 are transmitted efficiently to the web database through a wireless connection, and their accuracy has been verified by comparing them with the values displayed on the OLED screen.

Overall, the web interface designed to monitor TPM and infusion capacity in patient rooms functions as expected. The patient data update feature also operates smoothly, as evidenced by functional testing results that reached 100%. Additional testing for transmitting drop data from the web to the servo shows that the system can control the servo based on incoming data, adding further control capabilities to the infusion monitoring system.

The testing outcomes were then compared to previous studies by Gumilar et al. [5] and Siti Nur Khasanah et al. [16], which reported accuracy levels of 2–3%. The system developed in this research achieves a significantly improved performance, with an average error of 0.56% for the drop sensor and 0.6–1.58% for the weight sensor indicating up to a 50% performance improvement compared to earlier systems. Moreover, the data transmission response time to the server was recorded at less than one second, supporting real-time monitoring capability.

4. Conclusion

Based on the research that has been conducted, several conclusions can be drawn. The IoT-based infusion monitoring and control system proved effective in addressing challenges associated with manual infusion monitoring, demonstrating very high accuracy with minimal sensor error, namely 0.56% for the Correlation Photoelectric Speed Count sensor and 0.6% –1.58% for the load cell sensor. The NodeMCU ESP8266 was able to consistently transmit data to the web database every minute for one hour, and the transmitted data could be accessed and analyzed effectively through the website, enabling nurses and medical staff to monitor infusion conditions in real time. The system is also equipped with an alert feature for the infusion bag's weight capacity, which functioned effectively in helping nurses replace the bag at the appropriate time, while the control feature allowed the regulation of infusion drip rates based on commands sent from the website. Servo testing further confirmed the system's ability to adjust the infusion rate reliably. Overall, the automated infusion monitoring system reduces the risk of human error, improves monitoring efficiency, and ensures optimal patient care. In addition, it supports better workload management for nurses, contributing to enhanced healthcare service quality. Practically, the system holds strong potential for integration into Hospital Information Systems (HIS) as a smart infusion monitoring module, supporting healthcare digitalization and improving operational efficiency within medical institutions.

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