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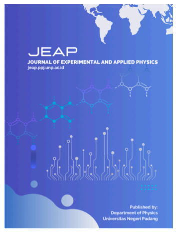

An Infusion Monitoring System With An Internet Of Things Based On Smartphone

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Abstract: Infusion is one of the most commonly used therapeutic methods in clinical practice. Improper monitoring of infusion fluid volume can lead to patient harm, such as air embolism when the fluid runs out and is not immediately replaced. In Indonesia, infusion monitoring is still performed manually. Previous studies have developed infusion monitoring devices using Arduino; however, these devices generally lack remote monitoring capabilities and tend to utilize microcontrollers inefficiently. To address these limitations, an IoT-based infusion monitoring system was designed using the NodeMCU ESP8266. The proposed system measures the number of infusion drops via an optocoupler sensor and determines the remaining fluid volume using a load cell sensor. Measurement data can be accessed in real-time through a smartphone, enabling remote monitoring. The innovation of this system lies in the integration of Internet of Things (IoT) technology for efficient remote control and monitoring. Performance evaluation shows that the average accuracy of the infusion rate (drops per minute) is 98.89%, while the average accuracy of the remaining fluid volume measurement is 96.8%, both demonstrating high reliability. This system provides an efficient and controlled solution for infusion management. The integration of IoT technology in this research establishes a foundation for the development of advanced infusion monitoring systems, contributing to improved patient safety and care in modern healthcare environments.

Keywords: Infusion, Load Cell, Optocoupler, Smartphone

1. Introduction

Infusion is among the most frequently used medical mechanisms as a therapeutic. Infusion is one of the means of rapid treatment in addition to medicine [1]. Infusion is carried out by introducing the ingredients of the solution into the body continuously or momentarily so as to get the effect of the treatment quickly. The materials included are in the form of blood, fluids, and medicines [2]. The administration of infusion fluids aims to replenish the body's lost nutrients or liquids [3]. When giving infusions for patients,

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extreme calculations is accurate and meticulous monitoring of infusions are needed by existing rules with the aim of preventing fatal symptoms in patients [4]. The delay in replacing the infusion fluid in the patient is a fatal mistake. Incidents like this can result in the blood fluid of the patient being sucked out of the infusion line [5].

Prior work in [6] presented an infusion monitoring device utilizing an Arduino Mega platform. The system incorporated a photogate sensor to measure infusion drop rate (drops/min), a load cell to estimate the remaining fluid volume, and a buzzer that provided an audible alert when the infusion fluid was nearly depleted and required immediate replacement. The device displayed system information on a TFT LCD. However, the design in [7] was limited to local notifications, as the use of only a buzzer and LCD did not support remote monitoring.

To overcome these limitations, this study proposes an IoT-based infusion fluid monitoring system capable of transmitting real-time data to a smartphone. The system monitors the percentage of remaining infusion fluid in the infusion bag and visualizes this information through a mobile application. Additionally, a notification feature is integrated to warn caregivers when the infusion supply approaches depletion and must be replaced promptly. The implementation of the Internet of Things (IoT) provides continuous data access, enhanced connectivity between devices, and supports remote supervision, thereby improving rapid response and clinical efficiency [8].

An optocoupler sensor is employed as an object-detection and timing measurement device. The optocoupler consists of an infrared emitter and a phototransistor detector, enabling it to determine the duration of beam interruption caused by a passing object, which is relevant for detecting infusion drop events. According to, the sensor is capable of measuring interruption durations associated with both high-speed and low-speed objects. The sensor produces a digital output ranging from 0 to 5 V, When the infrared beam is blocked and does not reach the phototransistor, the output is 0 V when the beam reaches the detector, the output ranges between 0 and 5 V. This binary response enables reliable detection of drop occurrences within the proposed monitoring system [9].

In the proposed infusion fluid monitoring system, an optocoupler is employed to detect infusion drop events. The infrared emitter and phototransistor detector are positioned on opposite sides of the infusion drip chamber. As each drop passes through the optical path, it interrupts the infrared beam, producing a voltage change that is transmitted to the microcontroller for drop counting. A predefined drop-rate set point is used as a reference against the measured value. When the system operates within the desired threshold, the controller automatically maintains the infusion drip rate at the specified value [10].

Load cells are commonly utilized in industrial applications requiring precise mass measurement. A load cell typically consists of a metal spring element integrated with strain gauges, including piezoelectric-based gauges. The electrical output of the load cell corresponds to the applied force on the mechanical spring, which induces deformation and produces a resistance change in the strain gauges. This resistance change is linearly proportional to the applied load [11].

A standard load cell contains four color-coded wires: the red wire as the excitation voltage input, the black wire as ground, the green wire as the positive output, and the white wire as the negative output. The strain gauges are arranged in a Wheatstone bridge configuration, where the conductivity of the bridge varies proportionally with the applied force. Under no-load conditions, the resistances of the bridge remain balanced; however, when a load is applied, the bridge becomes unbalanced, producing a differential output voltage [12]. The output voltage of the Wheatstone bridge is expressed as the magnitude of the output signal (Vo) is found in Equation 1.

$$V_o = \left[\frac{R_2}{R_1+R_2} - \frac{R_4}{R_3+R_4}\right] V_{EX} \quad (1)$$

From equation 1, the output signal from the sensor is usually only in the order of millivolts. Therefore, an amplifier circuit is required before use. In the use of the load cell sensor must use the HX711 module. The HX711 principle of converting the measured voltage in the change of resistance into the magnitude of the voltage through the circuit in the module. The implementation of a load cell in measurement systems requires the use of an HX711 module. The HX711 operates as a high-precision analog-to-digital converter (ADC) that converts the voltage variations resulting from resistance changes in the strain gauges into corresponding digital values. The module integrates several electronic components, including resistors, capacitors, transistors, and the HX711 integrated circuit, which functions as a regulator, amplifier, and oscillator to generate a stable digital output signal [13].

NodeMCU is an open-source firmware accompanied by a development kit based on the ESP8266 microcontroller. NodeMCU has a very compact form factor, with a length of 4.83 cm, a width of 2.54 cm, and a weight of approximately 7 grams. In addition to its small size, the board is relatively affordable. Despite its compactness and low cost, NodeMCU is equipped with an integrated Wi-Fi module and openmsource firmware, providing high flexibility for the development of Internet of Things (IoT) applications. The ESP8266 is widely adopted in IoT implementations because of its low cost and integrated wireless communication capabilities [14].

The Internet of Things (IoT) is an evolving technological paradigm that enables devices to communicate, exchange, and process data over internet-based networks without requiring continuous human computer interaction. This paradigm integrates smart sensors, actuators, and intelligent embedded systems into a connected ecosystem that supports automation, operational efficiency, and adaptive decision-making across diverse application domains [15].

ThingSpeak is an open-source IoT platform that provides an Application Programming Interface (API) for uploading, storing, and retrieving data via the HTTP protocol. The platform supports real-time sensor data acquisition, data analytics, geolocation services, and seamless integration with various web-based applications and social media platforms, thereby facilitating comprehensive IoT system development and cloud-based monitoring. Data transmission from the sensor readings can be received by the ThingSpeak platform with a minimum update interval of 15 seconds. For data retrieval, users may access the Export Data feature available in their ThingSpeak account and download the recorded dataset. The exported file is provided in .csv format, which can be opened and processed using common office or data-analysis software such as Microsoft Excel [16].

The idea of the "Internet of Things," or "IoT," aims to increase the advantages of permanently connected internet connectivity. [17]. According to the idea of the "Internet of things," any object with a network connection can send data without involving a person [18]. The internet of things is used as a means of storage based on data obtained from sensors [19]. In this study, using the smartphone as a display, the smartphone functions to collect data developed specifically for analysis and storage. Apart from being a means of communication, the smartphone also functions as a measurement system [20].

2. Materials and Method

This research is classified as engineering research. Engineering research is research that incorporates science into a design to achieve performance that meets predetermined objectives. The flow chart of the research that has been carried out is shown in Figure 1.

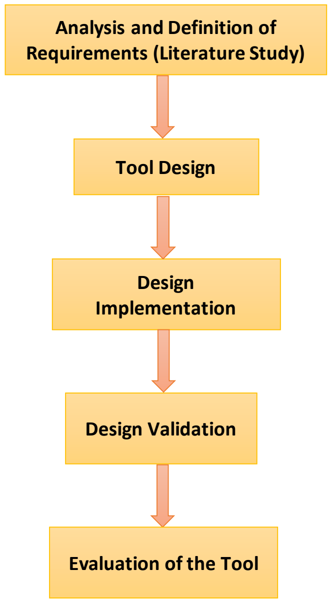

Figure 1. Research Methodology Flowchart

Figure 1 shows some of the procedures carried out in this study, including Analysis and Definition of Needs (Literature Study), Tool Design, Design Implementation, Design Validation, and finally the tool evaluation stage [21]. The tools and used of materials used in this study are personal computers (PC), and PC functions to create programs on Node MCU with Arduino IDE software. Some of the components used are NodeMCU, load cell sensors, optocoupler sensors, and motor servos.

This study used data collection techniques by measuring the amount of physics contained in the system. The measurement technique is carried out in includes ways, namely, measurement directly and indirectly. Direct measurement is a measurement that does not depend on other magnitudes. Indirect measurement is the measurement of a number whose value is influenced by other magnitudes and whose value cannot be obtained directly from the results of the measurement. The data obtained directly is the mass of the infusion. While data obtained indirectly includes the number of infusion drops and the percentage of the rest of the infusion.

The infusion fluid monitoring system design consists of hardware design and design of software. The software design serves as an instruction for the hardware to perform its duties. The hardware serves to explain the physical part of the system of infusion fluid monitoring design. The design of the hardware on the infusion fluid monitoring system. The hardware design of the system of infusion fluid monitoring can be seen in Figure 2.

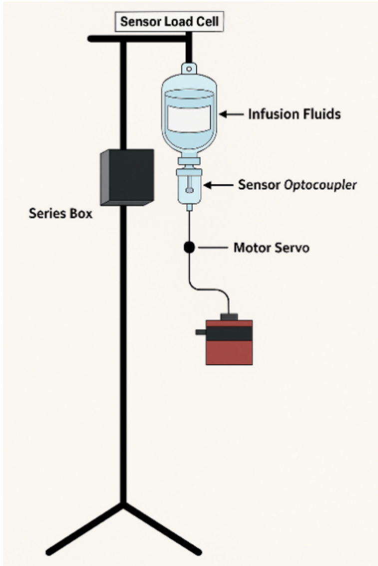

Figure 2. Hardware Architecture of the Infusion Fluid Monitoring System

Figure 2 contains a circuit box containing a series of ESP8266 nodes connected to a load cell, optocoupler, and servo motor. The optocoupler sensor is located attached to the drip tube to detect the infusion droplets in order to calculate the number of infusion drops per minute. The servo motor is located attached to the infusion hose. The bottle of infusion will be suspended from the load cell sensor to act as a load on the sensor. The block diagram of the design of the infusion fluid monitoring system with an Internet of Things-based smartphone display can be see in Figure 3.

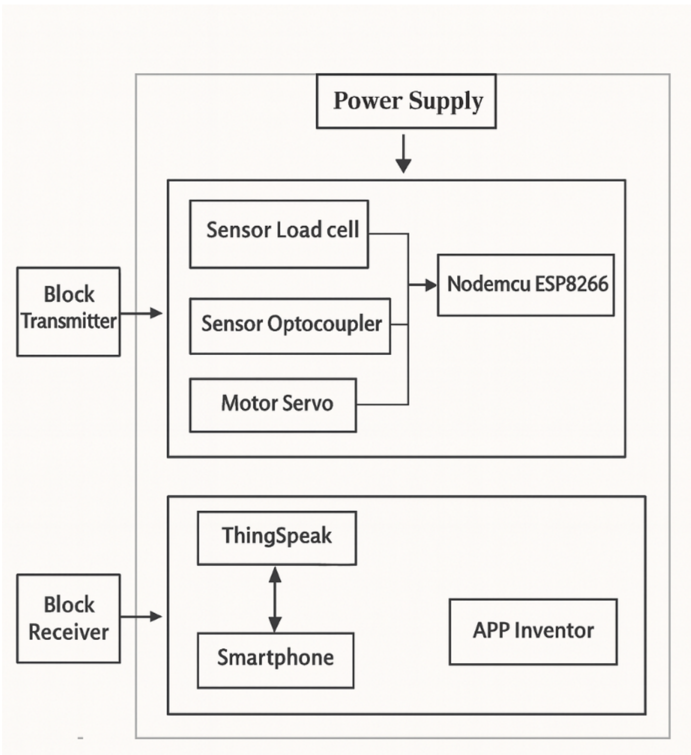

Figure 3. System Diagram Block

Figure 3 the load cell sensor is used for the sensor to detect the percentage of the remaining infusion, while the optocoupler sensor is used to detect infusion droplets per minute, and the servo motor is used to control the number of infusion drops. These three components will be connected to a NodeMCU. The sensor will be programmed using the Arduino programming language. The program will be connected to the existing wifi network. Once connected, the data will be sent to the cloud. The cloud used is ThingSpeak. After that, the display on the smartphone is programmed using the App Inventor application and the display on the smartphone. The monitoring data for drops per minute and the amount of remaining infusion fluid will be shown on the smartphone. Software design using App Inventor is shown in Figure 4.

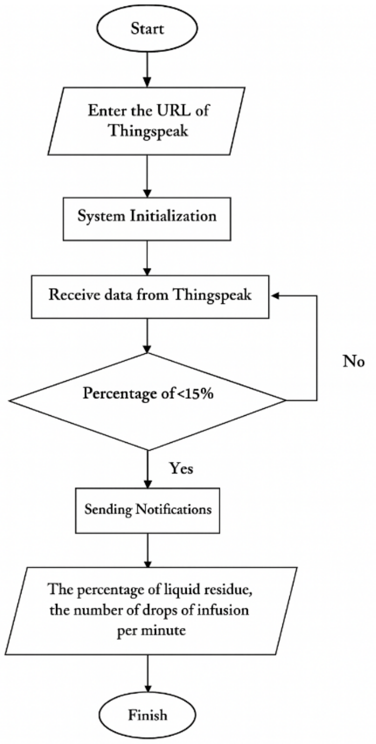

Figure 4. Software Design

Figure 4 is the flow of the App Inventor software. With the initial step of entering the URL of Thingspeak or the cloud. After that, the data contained in Thingspeak is defined in the App Inventor. Then the data on the percentage of the remaining liquid and the number of drops of infusion can be displayed.

3. Results and Discussion

The design result that has been carried out is an Internet of Things-based infusion monitoring system with a smartphone display. The tool is able to calculate the proportion of remaining infusion fluid and the rate of infusion droplets per minute. Measurement outcomes will be shown on a smartphone. The form of a mechanical on system in the monitoring of infusion fluid is shown in Figure 5.

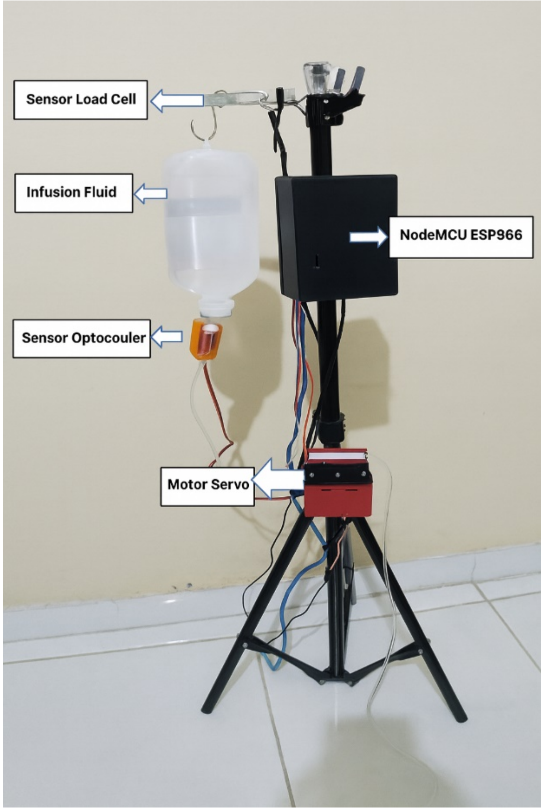

Figure 5. Infusion Fluid Monitoring System

Figure 5 is the results of a mechanical design that has been made to produce a system of infusion fluid monitoring with a smartphone display consisting of a series of electronic systems that build a system to count the number of infusion drips per minute and gauge the amount of residual infusion fluid. The measurements are carried out using a load cell sensor and an optocoupler sensor. The ESP8266 MCU node is coupled to the servo motor, optocoupler, and load cell sensor. The monitoring system operates by reading the results of measurement from the sensor and displaying them on the smartphone once it is turned on. The display on the smartphone shown in Figure 6.

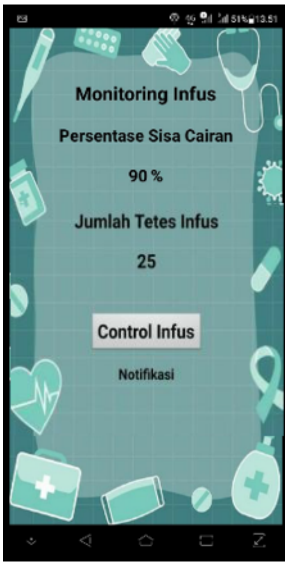

Figure 6. Smartphone Display Infusion Fluid Monitoring System

Figure 6 displays of system the number of droplets per minute of a measured set of infusion fluids and displays the remaining infusion fluids of a single infusion set displayed in percentage form. Instrument testing is carried out by evaluating the sensor output and the precision of the measurement equipment. Measurement of the number of drops per minute is carried out using an optocoupler sensor. The position of the sensor is placed very precisely at the point of fall of the droplets of the infusion fluid, when it is not so likely that the liquid droplets will not be detected by the sensor. The measurement of the percentage of residual infusion fluid is measured using a load cell sensor where the sensor will read changes in the load of the infusion. When the percentage of remaining infusion fluid shows 15% then a warning notification will appear on the smartphone as a warning sign that the infusion is running out and must be replaced immediately. Testing is complete to determine whether or not the measuring device has been successful in reaching the objectives that have been specified in research. Testing the load cell sensor's output value yielded a very low output, measured in millivolts (mV) [22]. The results of test shown in the graph in Figure 7.

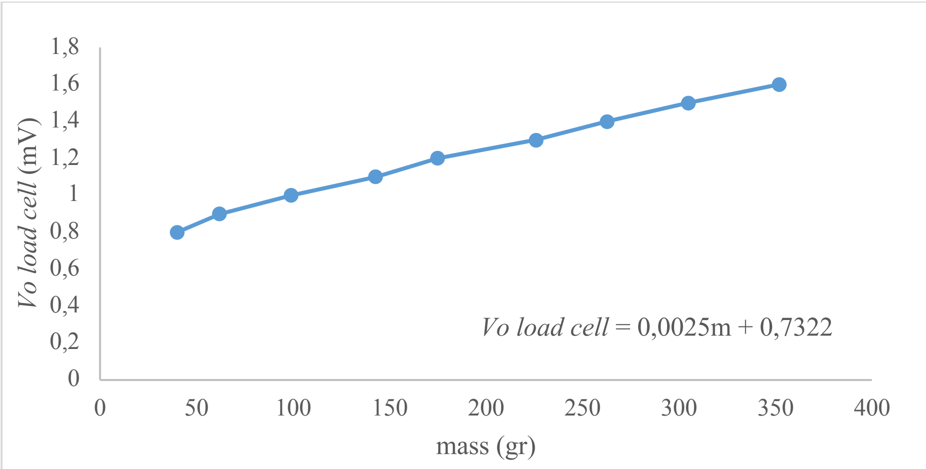

Figure 7. Relations of Load Cell Output Voltage with Mass

Based on Figure 7, the graph can be concluded that the relationship between the mass and the output voltage of the load cell sensor is directly proportional, the greater the mass, the greater the output voltage [23]. The figure illustrates the relationship between mass in grams and the load cell output voltage in millivolts. Physically, this graph represents how the load cell converts a mechanical quantity force into an electrical quantity voltage. As the mass increases, the force exerted on the load cell also increases, causing greater strain on its metallic element. This strain results in changes in the resistance of the strain gauges, which subsequently alter the output voltage of the Wheatstone bridge circuit. Because the relationship between force and strain is linear within the elastic region, the output voltage also increases linearly, as reflected in the graph.

The figure demonstrates a linear correlation between mass (m) and the output voltage (Vo). Based on the plotted data, the obtained calibration equation indicates that the output voltage increases proportionally with the applied mass. This behavior aligns with the fundamental principle of strain gauges, in which the force generated by mass produces strain in the elastic element of the load cell, altering the resistance and consequently producing a corresponding change in bridge output voltage.

The slope of the line, 0.0025 mV/gram, represents the sensor sensitivity, indicating the magnitude of voltage change generated for each unit increase in mass. Meanwhile, the intercept value of 0.7322 mV represents the offset voltage under no-load conditions, which commonly arises from the initial characteristics of the strain gauges or environmental influences. Overall, the data distribution closely follows a linear pattern, indicating that the load cell operates within its linear region, allowing the sensor response to be considered stable and predictable. This suggests that the system demonstrates good measurement performance and is suitable for calibration or mass measurement within the specified operating range. Results of testing the effect of gap width on the number of drops per minute in the graph in Figure 8.

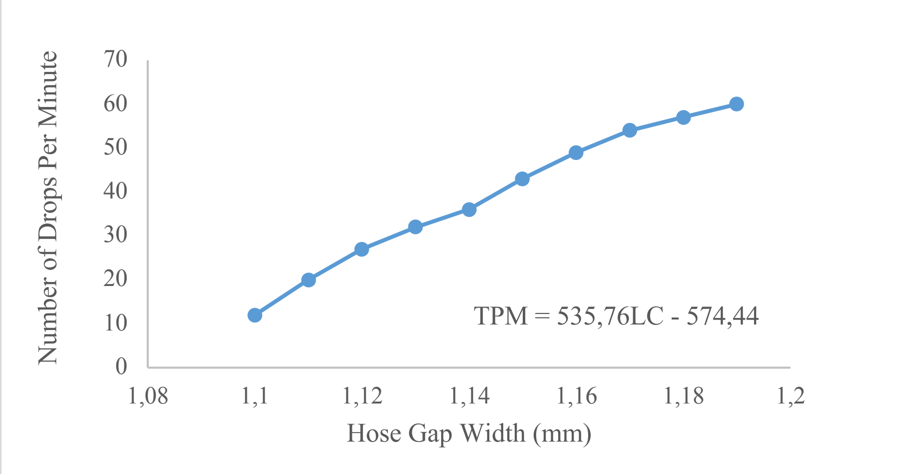

Figure 8. Relations of Hose Gap Width with Number of Drop Per Minute

Based on Figure 8 illustrates the relationship between the hose gap width (mm) and the number of drops per minute in an infusion flow system. The data indicate that the drop rate increases as the hose gap width becomes larger, forming an approximately linear trend. The regression equation demonstrates that even a small change in the gap width has a significant effect on the drop rate; an increase of approximately 0.01 mm in the hose gap results in an additional 5–6 drops per minute [24]. The testing was conducted by varying the infusion hose gap width in increments of 0.01 mm. This small variation was selected due to the high sensitivity of the drop rate to changes in the hose gap width, allowing for more accurate measurement results. The hose gap width was measured using a micrometer screw gauge.

From a physics perspective, this behavior is consistent with the principles of viscous fluid flow. Increasing the hose gap width enlarges the effective cross-sectional area through which the fluid passes, thereby reducing flow resistance and increasing the volumetric flow rate. Under the assumption that the hydrostatic pressure of the infusion reservoir remains relatively constant, this expansion directly increases the flow rate. Because the drop rate is proportional to the volumetric flow rate, a wider hose gap produces a higher number of drops per minute. The observed linearity suggests that the system operates under stable flow conditions, likely within the laminar flow regime, where geometric modifications to the flow path generate proportional changes in flow behavior.

This consistency indicates that the hose gap width serves as a highly sensitive and controllable parameter for regulating infusion drop rates. Consequently, the figure confirms that adjusting the hose gap width provides an effective physical mechanism for precise flow control in both automated and semi-automated infusion systems. Testing the accuracy in determining the residual infusion fluid percentage is carried out by weighing the infusion fluid with a varying mass. The remaining infusion fluid percentage is calculated by comparing the measured mass with the total mass. The results of testing the accuracy of the percentage of residual infusion fluid are shown in Table 1.

Table 1. Accuracy of Percentage of Remaining Infusion Fluid

Mass (gr)	Measured Percentage (%)	Calculated Percentage (%)	% Error	%Accuracy
524	100 %	100 %	0%	100 %
476	90 %	91 %	1,09%	98 %
423	80 %	81 %	1,23%	98 %
372	70 %	71 %	1,40%	98 %
318	60 %	61 %	1,63%	98 %
266	50 %	51 %	1,96%	98 %
213	40 %	41 %	2,43%	97 %
162	30 %	31 %	3,22%	96 %
110	20 %	21 %	4,76%	95 %
57	10 %	11 %	9,09%	90 %
Average			2,68%	96,8 %

Based on Table 1, the measurement results obtained are the value of accuracy in testing the accuracy of the remaining percentage of infusion fluid is 0,96 with a relative error of 2,68%. This shows that the system has good accuracy. The inaccuracies observed in the mass measurement results in this study are primarily attributed to instrumentation limitations and physical factors inherent to the system. The resolution and precision of the weighing instrument constitute the dominant sources of uncertainty, as noise, drift, and quantization errors can introduce both constant and relative deviations in the measured mass, directly affecting the resulting percentage error. In addition, imperfect zero calibration may generate a systematic offset if the tare value changes over time.

Several discrepancies also arise from fluid retention on the bottle and hose surfaces due to adhesion and capillary forces, causing the measured mass to decrease nonlinearly relative to the actual discharged volume. Mass loss through evaporation although minimal remains detectable, particularly at low volumes. Geometric and orientation factors of the container further influence fluid distribution, such as liquid trapped in specific regions, resulting in deviations between the effective measured mass and the ideal conditions. The presence of air bubbles can alter local density and subsequently affect mass readings.

Environmental temperature variations may also modify the fluid density and introduce minor buoyancy effects in high-precision measurements. Moreover, when percentage accuracy is derived through mathematical models or flow sensors, model limitations such as linear-flow assumptions that do not fully represent real conditions can contribute to additional systematic deviations. Overall, the combination of these factors explains the observed discrepancies between measured and calculated values presented in the accuracy table.

The process of testing the accuracy of the number of infusion drops per minute is carried out by comparing the readings of the number of drops in the system that has been designed with the calculation of the number of drops manually. Accuracy testing is performed by varying the gap width of the infusion hose to determine the number of drops using a stopwatch. The calculation of liquid droplets is carried out manually by setting the roller clamp on the infusion hose by counting the number of droplets that fall for 1 minute. The results of testing the accuracy of the number of drops per minute can be seen in Table 2.

Table 2. Accuracy of The Number of Infusion Drops

Infusion Hose Gap Width (mm)	Calculated (DPM)	Measurable (DPM)	% Error	%Accuracy
1,10	12	12	0,00 %	100 %
1,11	20	20	0,00 %	100 %
1,12	28	27	3,58 %	96,42 %
1,13	31	32	3,22 %	96,77 %
1,14	36	36	0,00 %	100 %
1,15	42	43	2,38 %	97,61 %
1,16	49	49	0,00 %	100 %
1,17	55	54	1,81 %	98,18 %
1,18	57	57	0,00 %	100 %
1,19	60	60	0,00 %	100 %
Average			1,09%	98,89 %

Based on Table 2, The process of testing the accuracy of the number of infusion drops per minute is carried out by comparing the readings of the number of drops in the system that has been designed with the calculation of the number of drops manually. Accuracy testing is performed by varying the gap width of the infusion hose to determine the number of drops using a stopwatch. The calculation of liquid droplets is carried out manually by setting the roller clamp on the infusion hose by counting the number of droplets that fall for 1 minute. From a fluid mechanics perspective, increasing the hose gap width directly affects the effective cross-sectional area of the flow. As the gap widens, flow resistance decreases, resulting in an increased fluid discharge rate. This behavior is consistent with the continuity principle and the characteristics of laminar flow, in which small geometric modifications to the flow channel lead to proportional changes in flow rate. Since the number of drops per minute is proportional to the volumetric discharge rate, the increase in flow rate directly contributes to a higher drop formation frequency.

Minor deviations observed in certain measurements, such as at gap widths of 1.12 mm and 1.13 mm, which produced errors of 3.58% and 3.22%, respectively, remain within acceptable limits. These deviations may be attributed to variations in fluid viscosity, mechanical tolerances in the gap adjustment mechanism, or transient fluctuations during the droplet formation process. Nevertheless, the average error remains low at 1.09%, with an overall accuracy of 98.89%. These results indicate that the system operates under stable physical conditions and that the sensor response is consistent across the entire testing range.

The result of the specification of the performance of the tool is the infusion fluid monitoring system. The results of the mechanical design that has been made to produce an automatic infusion fluid monitoring system, consisting of a series of electronics, have built a system for measuring the percentage of remaining infusion fluid and measuring the number of infusion drops per minute. This tool consists of an infusion pole. On the infusion pole, there is a circuit box containing the NodeMCU ESP8266 circuit connected to the load cell, optocoupler, and servo motor. The infusion bottle that is placed hangs on the load cell sensor as a measure of the percentage of liquid residue. The output of the load cell sensor is in the form of resistance. With the presence of a microcontroller circuit, the sensor output changes to voltage, so that when the sensor detects a change in mass in the object, there will be a voltage change in the sensor [25]. The optocoupler sensor is located attached to a drip tube to detect infusion droplets to then calculate the number of infusion drops per minute, in accordance with the working principle of the sensor, namely, the sensor has a high voltage if the infrared on the sensor does not hit the phototransistor [26]. The measurement results are displayed on a smartphone so that they can be accessed anywhere and anytime.

The infusion monitoring system developed in this study exhibits several strengths and limitations. One notable advantage is its ability to determine the drip rate without requiring manual timing over a one-minute interval. Once the set point is configured, the system automatically measures the infusion drip rate in accordance with the predefined value. Another significant benefit is the automated monitoring of the remaining infusion volume. This feature reduces the need for nurses to frequently enter the patient's room, thereby minimizing disturbances to the patient and family. Furthermore, the automatic volume-tracking mechanism helps prevent negligence in replacing depleted infusion fluid, as the system issues a warning notification to the caregiver's smartphone when the infusion volume approaches a critical level. Despite these advantages, the system also has limitations. The mechanical structure of the prototype lacks rigidity, and the cable management is relatively unorganized, requiring users to handle the device with caution. These mechanical and structural constraints indicate the need for further refinement to enhance durability and reliability during clinical operation.

4. Conclusion

Based on the results of research and data analysis on the infusion fluid monitoring system that has been carried out, it was concluded that for the number of infusion drops, the average accuracy obtained was 0.98 with an average relative error of 1.09%. For measuring the percentage of remaining infusion fluid, an average relative error of 2.68% was obtained with an average accuracy value of 0.96. An infusion monitoring system with an Internet of Things (IOT) based smartphone display using NodeMCU ESP8266 has been successfully designed and tested. This monitoring system is able to detect the number of infusion fluid drops per minute and measure the percentage of remaining infusion fluid, so it can help medical personnel by communicating quickly via smartphone.

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