Journal of Electronics, Electromedical Engineering, and Medical Informatics
Multidisciplinary: Rapid Review : Open Access Journal e-ISSN: 2656-8632

RESEARCH ARTICLE OPEN ACCESS

Manuscript received December 21, 2021; revised January 5, 2022; accepted January 6, 2022; date of publication January 21, 2022
Digital Object Identifier (DOI): https://doi.org/10.35882/jeeemi.v4i1.5

Analysis of the Drop Sensor Accuracy in Central Peristaltic Infusion Monitoring Displayed on Computer-Based Wireless Using TCRT 5000 Drop Sensor

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ABSTRACT In some hospitals, the infusion is still done manually; medical staff observes fluid drip directly and then controls its rate using a mechanical resistor (clamp). This method is certainly far from the level of accuracy. An infusion pump is a medical aid that controls and ensures the correct dose of infusion fluid is given to patients under treatment. This study aims to analyze the accuracy of the TCRT5000 as a drop sensor based on readings of the infusion pump monitoring system. This module consists of a TCRT5000 drop sensor module, comparator circuit, monostable circuit, stepper motor, L298N motor driver, and ATmega328 microcontroller. The TCRT 5000 sensor detects the droplets, then amplified by a comparator and monostable circuit, then the flow rate and remaining volume readings are generated by the ATmega328 microcontroller. Furthermore, this data is sent via wireless HC-11. The flow rate shows that the highest error value is 4% at the 30 ml/hour setting, and the lowest error value is 1% at the 60 ml/hour setting. While the flow rate measurement results using an Infuse Device Analyzer, the highest error value is 2,2% at the 30 ml/hour setting, and the lowest error value is 0,58% at the 100 ml/hour setting. This infusion pump monitoring is designed centrally to facilitate the nurse's task in accurately monitoring the infusion dose given to the patient.

INDEX TERMS Infusion Pump, Central Monitoring, TCRT 5000, Wireless.

I. INTRODUCTION

In the manual infusion systems arrangement, a clinician observes fluid drip directly and controls its rate using a mechanical resistor (clamp) [1]. Manual infusion systems fill a critical gap in low resource settings but are less than optimal, as they are more labor-intensive, less reliable, may require expensive proprietary disposables, and some systems lack flow rate and dose adjustability [2][3][4]. These factors are critical barriers to providing high-quality, effective medical care in cases in which timing and dose accuracy are crucial [3]. A wrong administration rate has been shown consistently as the most significant problem in intravenous medication administration [5][6][7]. The concerns have also been raised that a proportion of wrong rate errors are due to poor calculation skills [8][9]. The clinician at the point of care, most often a nurse, is accountable for the final step of ensuring that the correct intravenous medication or infusion is being delivered [10]. The development and modification of nursing actions, especially in the setting of intravenous fluid administration, needs to be carried out [11]. A study from 2005 found a staggering 67% error rate with the administration of intravenous infusions in an Intensive Care Unit (ICU) [12][13]. Data support that up to 58% of all intravenous errors occur during the actual drug administration step, again relying on the human end-user at the human-device interface as the final step in ensuring safety [14]. The infusion pump is one of the developments of medical devices that automatically enter intravenous fluids into the patient's body [15]. This tool has a fairly important function in medical services, especially in critical patient care [16]. Often in a hospital, the number of patients is not balanced with the number of nurses, so the possibility of negligence in monitoring the patient's infusion fluid condition can occur [17]. Besides modification that the U.S. Food and Drug Administration (FDA) determines would not create undue covid risk nowadays is remote monitoring and manual control of infusion pump to manage the care of a patient without physically entering a patient's room [18][19]. Therefore, to overcome this problem, a tool is needed that can monitor the use of infusions centrally in hospitals so that the duties of nurses who are on guard can be facilitated while also preserving personal safety [17][18] [20].

Regarding the automation of the device, Bayu has proposed a central system of infusion monitor with volume and drop detection parameters per minute, showing a computer-based wireless delivery system[21]. He gave suggested designing sensors to be more sensitive. Then, the same device was made by Decoriza; it is an infuse pump monitoring-based wireless [22]. In that study, there are also less sensitive sensor constraints. After that, Alwa investigated a patient infusion volume and drop rate monitoring system using node MCU ESP8266 [23]. In that study, the development was used to improve the drop sensor to read droplets more accurately. Furthermore, the related research done by Matthew has investigated the risk of medication errors with infusion pumps [24]. From his study, it can be known that medication orders may have had incorrect or conflicting rates of dose information. Furthermore, the transcription of medication order was misinterpreted, erroneous laboratory test results led to the wrong rate. Additionally, medication was prepared as a volume greater or lesser than ordered. Still about the drop sensor, finally Layson developed an intravenous (IV) monitoring and refilling system [25]. Layson gave a recommendation that other photo-electronic sensors can be tested for possible replacement of the optic sensors in case the latter fail.

This is because user acceptance of technology is strongly influenced by how users perceive the technical performance (includes factors such as system reliability, speed, and accuracy) [26][27][28]. This device should be safety-critical, as it is used in hospital settings to provide accurate and reliable intravenous infusions to patients [29]. Serious patient outcomes are over-represented among intravenous medication administration errors compared with other adverse incidents [30]. Based on some research in advance, found that there are less sensitive drop sensors of infusion pumps. It can result in a wrong rate. Infuse fluid dose can be greater or lesser than ordered.

Based on the problems above, this study aims to analyze the accuracy of the TCRT 5000 module sensors to determine the drop rate in the infusion monitoring system to compare with IR LED-photodiode as a drop sensor is usually used. In the existing infusion pumps, the drop sensing unit consists of an IR-LED as transmitter and a matched phototransistor as a detector, fixed across the drip chamber to detect falling drops [31]. That is different from the TCRT 5000 sensor module; the I.R. transmitter, and reflector have a side-by-side placement. This study aims to analyze the drop sensor accuracy in central monitoring peristaltic infusion displayed on computer-based wireless (using TCRT 5000 drop sensor). In building the system, several components are needed, such as peristalsis on the mechanics of the infusion pump, the TCRT 5000 sensor for detection of fluid infusion drops, the HC-11 module as a wireless concept in the design.

II. MATERIALS AND METHOD

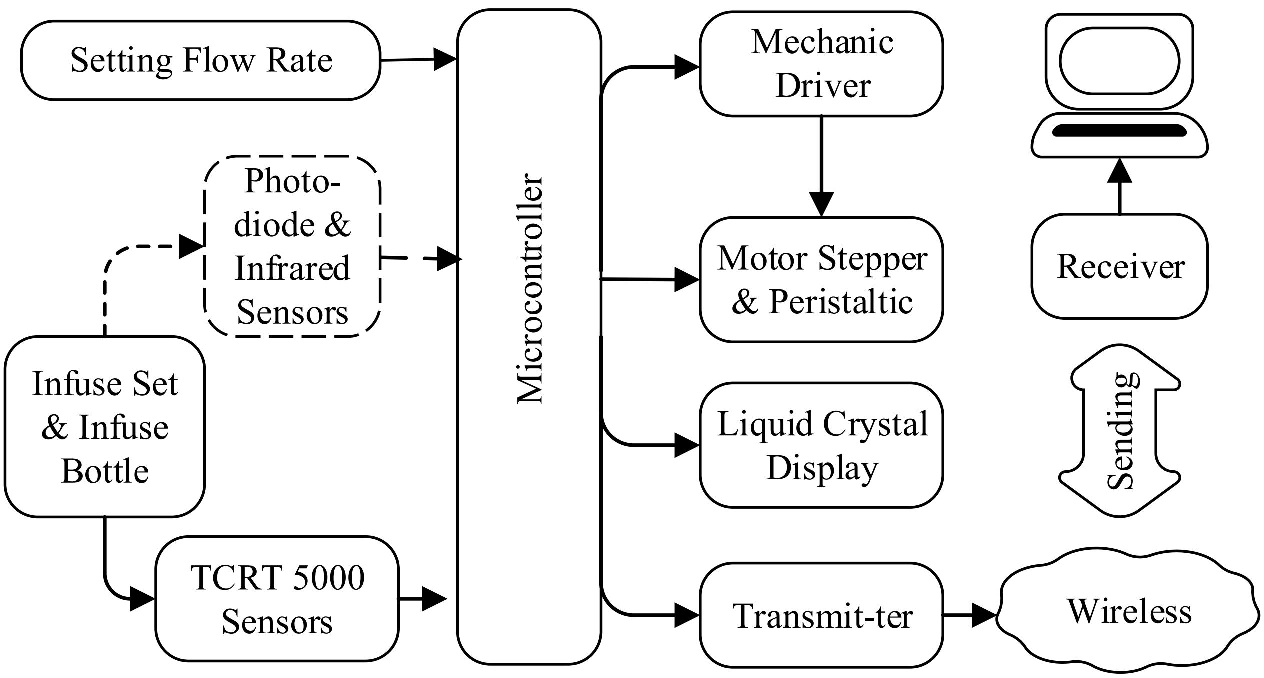

FIGURE 1. **The Diagram Block**

A.OBJECT

This study uses a Terumo infusion set with 20 drops/ml specifications, infusion volume of 500 ml, and infusion pump with TCRT 5000 module as drop detection. The readings on the infusion pump are sent to a computer via wireless HC-11. The data viewer on the computer uses the Delphi application. It also needs an infuse device analyzer or IDA 4 plus (Fluke, USA), used to calibrate the infusion pump device.

B.DATA ACQUISITION

This study contains the drop rate (drop/minute), the flow rate in a graph (ml/hour), and volume (ml). It used a flow rate setting of 30 ml/hour, 60 ml/hour, and 100 ml/hour with a 500 ml infusion fluid volume. The flow rate value can be saved on the computer in excel format, and the flow rate graph can be saved in the form of an image.

C.DATA PROCESSING

This study was built divided into analog circuits and a microcontroller as a data processor. The diagram block is shown in FIGURE 1., and the flowchart is shown in FIGURE 2.

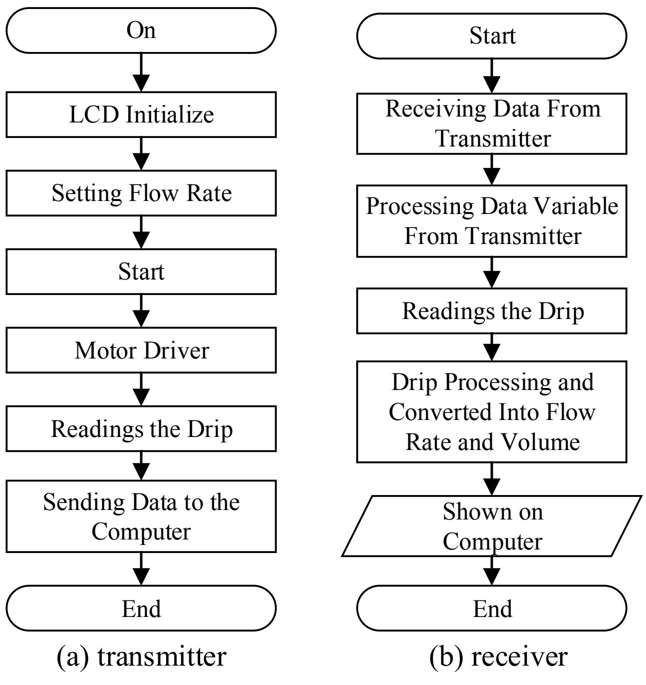

FIGURE 2. The Flowchart

The diagram blocks are shown in FIGURE 1. explain that setting flow rate is done to determine the rate of droplets per minute that will be used. The TCRT 5000 sensor detects droplets, then amplified by a comparator, and monostable circuit where the output is connected to a digital Arduino, analog data is converted to digital and then converted to drops in one minute, which will be converted in ml units. The microcontroller will provide input for the motor driver to drive the stepper and peristaltic motors according to the speed settings that have been adjusted to the flow rate settings. The microcontroller converts the droplets to flowrate. After that, the drops per minute are converted again to the infusion volume. The data processed by the microcontroller is sent to the computer unit by the HC-11 wireless module in the form of serial communication. The data displayed on the computer is numerical values and graphs, which will then be saved with the storage features available in the program.

The Arduino program was built based on the flowchart as shown in FIGURE 2. When the device is turned on, an initialization process occurs on the LCD, then the flow rate is selected as needed, which is 30, 60, or 100 ml/hour. The motor driver will run the motor according to the predetermined speed setting when pressed start. When the motor starts to move, the drop sensor activates and takes a droplet reading. The microcontroller system will convert the number of drops into the flow rate and volume. The microcontroller sent the data from the transmitter to the receiver serially to the computer. The receiver circuit receives serial data that has been sent by the transmitter circuit resulting from data conversion on the microcontroller module, then the flow rate reading results will be displayed on a computer in the form of a graphic display.

1. Drop Sensor Module (TCRT 5000)

The drop sensor module TCRT 5000 is used as a drop detection sensor. In the TCRT 5000 sensor module, an I.R. reflector and phototransistor are installed in parallel, and each functions as a light emitter and receiver. On the back of the sensor module, there is a potentiometer that serves to adjust the sensor's sensitivity. The output of the drip sensor circuit will be forwarded to the comparator circuit, which is entered at pin 3 of the LM741 IC.

2. Comparator Circuit

A comparator circuit is a set of comparators used to compare two values and then give the result, which is smaller and more prominent. A circuit of comparators on an Op-Amp will compare the incoming voltage on one input channel with the voltage on one input channel to another called the reference voltage. The circuit consists of the LM741 IC. The comparator circuit used the R1 (20K) multiturn to adjust the voltage reference. The smaller the resistance, the greater the voltage. The comparator can be used as a signal conditioner that generally compares the sensor's output signal and the reference voltage. The reference voltage is a voltage whose value is fixed. To calculate the reference voltage (Vreff), you can use the voltage divider formula as follows:

$$\text{Vreff} = \frac{R1}{R1+R2} \text{ x Vsupply} \quad (1)$$

If Vin+ > Vreff- then the output voltage = +Vsupply
If Vin+ < Vreff- then the output voltage = -Vsupply

3. Monostable Circuit

A monostable circuit is one of the developments of relaxation-type oscillators with triggers. The monostable circuit does not change until a pulse comes to the oscillator input line. This monostable circuit is connected to the comparator's output. This circuit uses the NE555 IC, and there is a multiturn R5

(100 K) to adjust the voltage on the monostable circuit so that the output matches the desired voltage and can detect droplets by infrared photodiode sensors. The output of this monostable circuit is connected to the Arduino digital pin.

The main concept of this circuit is to use the charging and discharging of the capacitor as the delay time. for the length of the delay can be calculated by the following formula:

$$TD = 1{,}1\ R.C \tag{2}$$

where T.D. is Time Delay (seconds), R: Resistor (Ohm) and C: Capacitor (Farad)

4. Motor Driver Circuit

The stepper motor driver circuit is used to activate the stepper motor. L298N obtain logic input (0 1 0 1), (10 0 1), (1 0 1 0), (0 110), generated by PIN8, PIN9, PIN 10, PIN 11. Furthermore, stepper motor speed is set by delay change of any input logic IC L298D; the faster delay logic changes then, the faster the turn of the stepper motor or vice versa. The diode serves as a backflow guard on the motor.

5. Wireless Module HC-11

This module uses wireless HC-11 is used as the sender and receiver of data from the infusion pump module, then the data will be displayed on the computer display includes volume, droplets, and flowrate (speed).

6. Microcontroller Program

In this study, the main programming for Arduino includes drop rate (drop/min) and flow rate (ml/hour) readings, also volume readings (FIGURE 3). The listing program for Arduino is shown in the Pseudocode. This study displayed the result on the computer using the Delphi application as shown as FIGURE 4. The programming includes a drop rate reading display program, flow rate reading display program, volume reading display program, saving program, and flow rate value data storage program in excel and flow rate graph data in the format picture. The listing program for Delphi was shown in the Pseudocode.

FIGURE 3. Infusion Pump Design

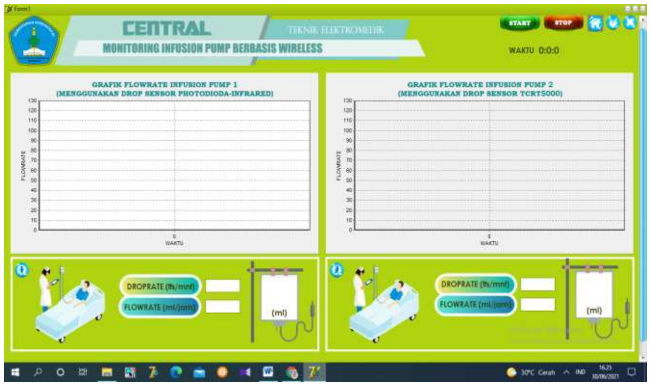

FIGURE 4. Delphi Display Program

D. DATA COLLECTION

After the module design was completed in this study, the drop sensor was tested by calculating the number of drop rates (drops/minute) at each setting and comparing it with the drop rate results (drops/minute) on the display module. Furthermore, a comparison of the readings of the flow rate and volume results on the display module is carried out with measurements using IDA (calibration). IDA's measurement results will be observed, and data will be taken ten times in 10 minutes or one time in every minute.

E. DATA ANALYSIS

After the drop rate, flow rate, and volume were collected ten times, then calculating its average and analysis the error value, deviation, standard deviation, and uncertainty data. The results are presented in the form of tables and graphs.

III. RESULT

In this study, TCRT 5000 module sensors have worked to detect droplets in the infusion pump. This drop sensor is shown in FIGURE 5. uses the infrared light reflection and phototransistor principle to determine its output value.

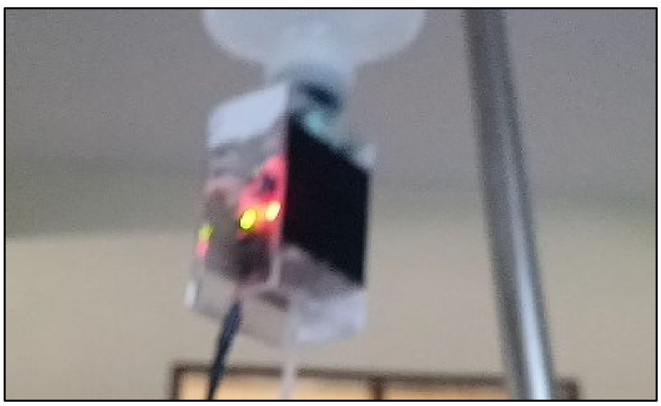

FIGURE 5. Infusion Pump Drop Sensor using TCRT 5000 Module

The motor driver module is used as a driver for stepper motors and speed regulators for motors. The design of infusion pump module with TCRT 5000 is shown on FIGURE 6.

The infusion pump has been tested using an Infuse Device Analyzer 4 Plus (Fluke, USA). The proposed design is shown in FIGURE 6.

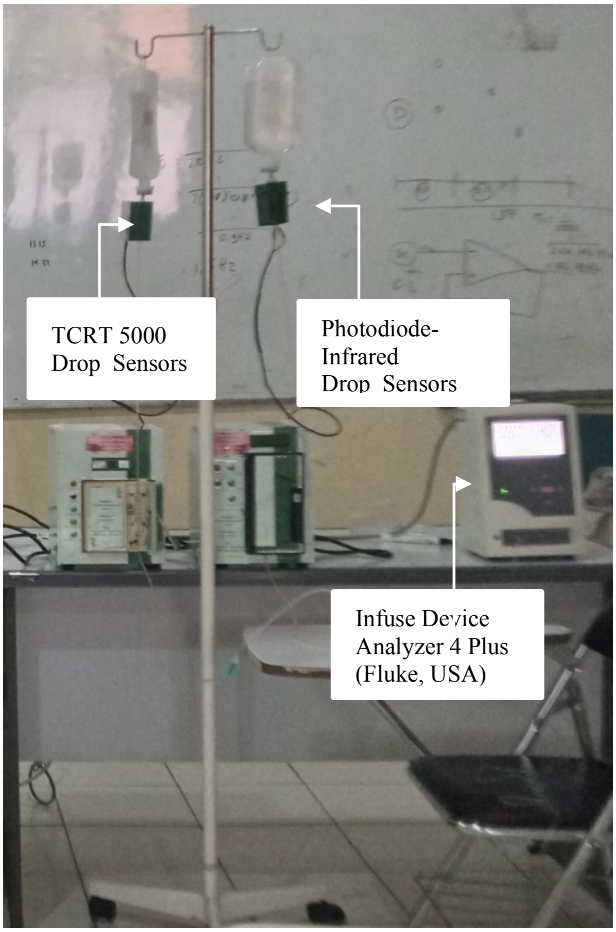

FIGURE 6. Design of Central Monitoring Infusion Pump

When the infrared light reflection is considered less, the phototransistor will be off, and the output terminal of the module will give a HIGH value. Suppose there is a light reflection that is considered adequate. In that case, the light intensity received by the phototransistor will be large enough to be in the on condition, and the module will give a LOW output (the led indicator will light up). HC-11 wireless module is used to send and receive data on the infusion pump module to display the data on the computer display.

A. INFUSION PUMP DROP RATE (DROP/MIN) MEASUREMENT

Data measurement of infusion pump drop rate then calculates the mean, error value, deviation, standard deviation, and uncertainty as shown in TABLE 1.

TABLE 1
The Error Of Drop Rate Measurement For Infusion Pump Design

Setting Flow Rate (ml/hour)	Mean (drop/ min)	Error (%)	Deviation (drop/ min)	SD (drop /min)	UA (drop/ min)
30	10,4	4	0,4	0,52	0,16
60	20,2	1	0,2	0,42	0,13
100	32,8	1,5	0,5	0,42	0,13

Then the percentage of error value obtain a graph as shown in FIGURE 7.

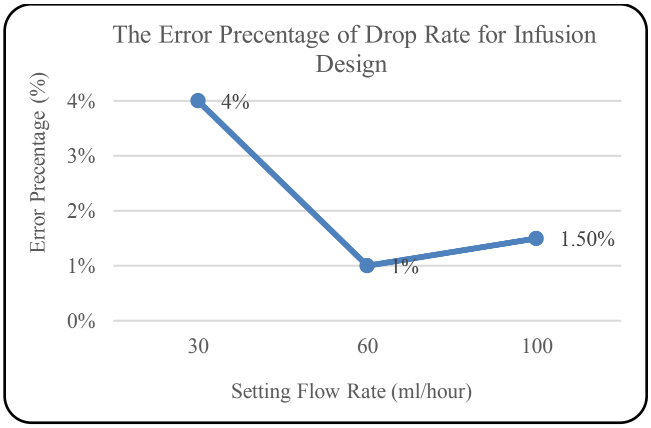

FIGURE 7. The Error of Drop Rate (drop/minute) Measurement For Infusion Pump Design

The data value results from the drop rate (drop/minute) are read on the LCD using the infusion set specification of 20 drop/ml Terumo brand. From the drop rate (drop/minute) for the infusion pump design with the TCRT 5000 drop sensor above, the enormous error value is found in the 30 ml/hour setting, which is 4%, while the slightest error is in the 60 ml/hour setting, which is 1%.

B. INFUSION PUMP FLOW RATE (ML/HOUR) MEASUREMENT

From data measurement of infusion pump flow rate, then the mean, error value, deviation, standard deviation, and uncertainty were calculated as shown in TABLE 2.

TABLE 2
The Error of Flow Rate (ml/hour) Measurement for Infusion Pump Design

Setting Flow Rate (ml/hour)	Mean (ml/hour)	Error (%)	Deviation (ml)	SD (ml)	UA (ml)
30	31,2	4	1,2	1,55	0,49
60	60,6	1	0,6	1,26	0,40
100	97,8	2,2	2,2	2,53	0,80

Then the percentage of error value obtain a graph as shown in FIGURE 8.

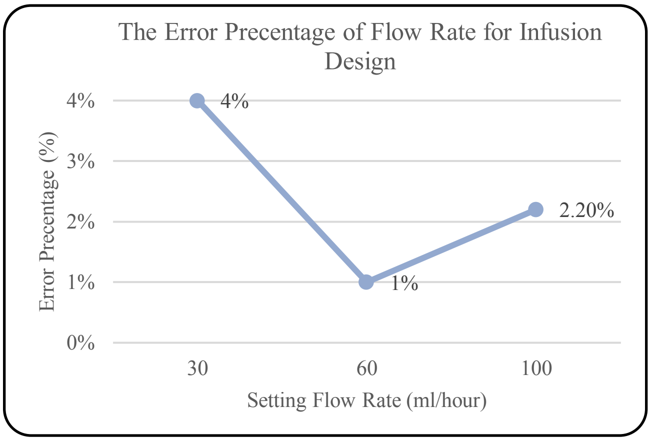

FIGURE 8. **The Error of Flow Rate (ml/hour) Measurement of Infusion n**

C. INFUSION PUMP FLOW RATE (ML/HOUR) MEASUREMENT USING INFUSE DEVICE ANALYZER

From the flow rate measurement using IDA, then the mean, error value, deviation, standard deviation, and uncertainty were calculated as shown in TABLE 3.

TABLE 3
The Error of Flow Rate (Ml/Hour) Measurement Between the Design and Calibrator (IDA 4 Plus, Fluke, USA).

Setting Flow Rate (ml/hour)	Mean (ml/hour)	Error (%)	Deviation (ml)	SD (ml)	UA (ml)
30	30,67	2,2	0,67	0,08	0,02
60	60,69	1,15	0,69	0,13	0,04
100	100,58	0,58	0,58	0,11	0,03

Then the percentage of error value obtain a graph as shown in FIGURE 8.

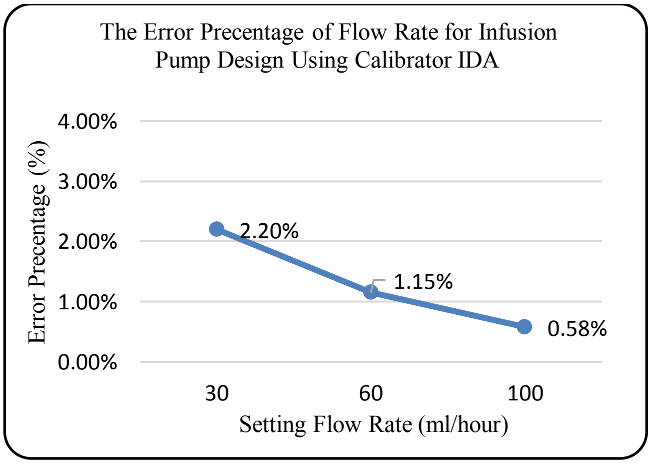

FIGURE 9. **The Error of Flow Rate (ml/hour) Measurement of Infusion Pump Using Infuse Device Analyzer**

From the flow rate measurement (ml/hour) using the IDA as shown in Fig. 17, the largest error value is found for the 30 ml/hour setting, which is 2.2%, while the minor error is in the 100 ml/hour setting, which is 0, 58%.

D. INFUSION PUMP VOLUME (ML) MEASUREMENT USING INFUSE DEVICE ANALYZER

The error measurement of infusion pump volume result using infuse device analyzer was shown in TABLE 4.

TABLE 4
The error of volume (ml) measurement between the design and calibrator (IDA 4 Plus, Fluke, USA).

Volume Remaining in Infuse Pump LCD (ml)	Error (%)
496	1
495	1
494	0,67
493	0,75
492	0,80
491	0,17
490	0,86
489	0,13
488	1,44
487	0,7
Mean Error (%)	0,75

As shown in TABLE 4, the data is a data analysis of infusion volume parameters. The data interpretation starts when the infuse device analyzer reaches volume measuring stability, which consists of the infuse volume remaining is 496 ml. It has the largest error value obtained in the remaining 488 ml volume of 1.4%, while the smallest error is in the remaining 489 ml volume of 0.13%, and the average error value is 0.75%.

E. WIRELESS TESTING

The wireless range of the infusion pump using the TCRT 5000 sensor was shown in TABLE 5.

TABLE 5
Wireless Testing With and Without Obstacle

Tx and Rx Range (m)	Without Obstacle	With Obstacle
1	Sent	Sent
2	Sent	Sent
3	Sent	Sent
4	Sent	Sent
5	Sent	Sent
6	Sent	Sent
7	Sent	Sent
8	Sent	Sent
9	Sent	Sent
10	Sent	Sent
11	Sent	Sent

12	Sent	Sent
13	Sent	Sent
14	Sent	Unstable
15	Sent	Unstable
16	Sent	Unsent
17	Unstable	Unsent
18	Unstable	Unsent
19	Unstable	Unsent
20	Unstable	Unsent
21	Unsent	Unsent
22	Unsent	Unsent

The wireless coverage without obstacles, the maximum distance of data that can be sent is 16 meters, above that distance, the transmission is unstable, and when the distance is above 20 meters, the data cannot be received by the transmitter. Meanwhile, when an obstacle is given in the form of a wall with data barriers, then the data can still be sent properly up to a distance of 13 meters. At a distance of 14 meters, the transmission has started to become unstable, and a distance above 16 meters is no longer able to receive data from the transmitter.

IV. DISCUSSION

The central peristaltic infusion pump monitoring appears computer-based wireless, by placing TCRT 5000 drop sensors module in a dark box, has been examined and tested in this study. Motor driver success to drive the stepper and peristaltic motors according to the speed settings that have been adjusted to the flow rate settings (30, 60, and 100 ml/hour). Based on flow rate measurement using Infuse Device Analyzer (IDA 4 Plus, Fluke, USA), the infusion pump used TCRT 5000 as a drop sensor has 2,2% error value on 30 ml/hour setting, 1,15% on 60 ml/hour setting, and 0,58% on 100 ml/hour setting. By comparing the error value of infusion pump using photodiode-infrared sensor, it shown a different error value, those are 5.97 % error value on 30 ml/hour setting, 1.13% on 60 ml/hour setting, and 2.48 % on 90 ml/hour setting [32]. In other journal, founds those are 4% error value on 30 ml/hour setting, 4% on 60 ml/hour setting, and 0,8% on 100 ml/hour setting [33]. This difference of error value can be influenced by several factors, including the stability of the stepper motor's rotation, the sensitivity of the sensor that has been made, and the placement of the sensor.

Even though it transmits data to help the nurse's task, it has range data limit well up to a distance of 16 meters, while when there is an obstacle, it can only transmit with a distance of 13 meters. Nurses perceive infusion pumps to enhance safe nursing practice [34]. However, there is no further development on the volume parameters such as warning alarm that the infusion fluid will run out, presence of a bubble, and occlusion. So, when the occlusion alarm is activated, the patient receives no or severely reduced infusion therapy [35].

In practice, central infusion monitoring appears computer-based wireless leads to facilitate the nurse's task in monitoring the infusion dose that is given to the patient in a nurse's station, so it can minimalize the possibility of nurse's negligence.

V. CONCLUSION

The purpose of this study is to conclude that a drop sensors accuracy in central peristaltic infusion monitoring using TCRT 5000 drop sensor has been analyzed. The error value is quite good from testing and measurement, not exceeding the tolerance limit of calibration. It leads to more simplicity and higher accuracy than using a photodiode-infrared sensor. From the IDA flow rate data processing, it has 2,2% error value on 30 ml/hour setting, 1,15% on 60 ml/hour setting, and 0,58% on 100 ml/hour setting. The following are some suggestions that can be considered for further improvement: adding parameters and settings can be used for several brands and types of infusion set sizes, increasing the accuracy of the tool to avoid any errors, and adding antennas to the system wireless to cover long distances.

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ATTACHMENT

[1.] Programs
https://drive.google.com/drive/folders/1JeE4Z7fi-6n-eAE8wUE1RTD1cEd0ivqI?usp=sharing

[2.] Schematic
https://drive.google.com/drive/folders/1RdPYwa24Mgyz6GENwIll_omDYBLMq2Km?usp=sharing