JURNAL ECOTIPE
Electronic, Control, Telecommunication, Information, and Power Engineering
Volume 12, Issue 1, April 2025, pp. 20-30
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v12i1.4541

PI Control Application for Low Speed Stepper Motor in Medical Infusion Pump for Flow Rate Stability

Muhammad Achsanul In'am[1], Nana Sutarna[2], Astri Era Hamijaya[3]
[1] Universitas Muhammadiyah Yogyakarta, Jl. Brawijaya, Kasihan, Bantul, Yogyakarta 55183, Indonesia
[2] Politeknik Negeri Jakarta, Jl. Prof. Dr. G.A. Siwabessy, Kampus UI, Depok, 16425, Indonesia
[3] Universitas PGRI Yogyakarta, Jl. PGRI I Sonosewu No. 117 Daerah Istimewa Yogyakarta 55182 Indonesia

ARTICLE INFO

Article historys:

Received : 02/02/2025
Revised : 14/02/2025
Accepted : 02/04/2025

Keywords:

Flow Rate; Infusion Pump; PI Control System; Stepper Motor

ABSTRACT

The infusion pump is an intravenous injection machine for administering high-alert drugs. Failure to administer this type of drug can result in patient death. One cause of failure is interference with the flow rate of infusion fluid, which is influenced by the performance of the stepper motor. This study proposes a PI control design for controlling the stability of the flow rate in an infusion pump machine. The tuning method used is the Ziegler Nicholes type 1 tuning method, and the creation of a first-order transfer function using the Cian Cone method. The system is also applied directly to the hardware and tested using an Infusion device analyzer. The simulation results show that PI control can reach the set point and remain stable with a rise time of 19.49 seconds and a settling time of 32.39 seconds. In actual testing of the infusion pump machine with PI control, the average flow rate accuracy level reached 98%, and its stability reached below 0.3 ml/hour. This proves that the infusion pump that was successfully created can be used to administer high-alert drugs appropriately according to the dose and can be used for a long time with constant delivery quality.

Corresponding Author:

Muhammad Achsanul In'am
Universitas Muhammadiyah Yogyakarta, Jl. Brawijaya, Kasihan, Bantul, Yogyakarta 55183, Indonesia
muhammad.achsanul@umy.ac.id

1. INTRODUCTION

Hospital service quality assurance standards are implemented through inpatient safety regulations. This includes fully procuring medical equipment to support more optimal patient treatment. The act of administering medication, especially high-alert medication, must be considered an aspect of patient safety [1]. Nurses still make errors when handling patients, especially when administering drug injections. The number of cases of errors in administering drug doses is relatively high, which results in patient death. In the United States, these cases reach as many as 48,000–100,000 per year. Meanwhile, in Indonesia, the percentage of cases reached 24.8 percent of reported cases [2]. Therefore, when administering medication, you must follow the ten principles of correct medication administration [3]. The ten principles are drug, dose, patient, route, time, information, expiration, assessment, evaluation and documentation.

One technique for administering high-alert-type drugs is through an intravenous infusion device. The action of administering high-alert drugs must be done carefully and precisely. On the other hand, until now, manual/conventional infusion models are still found and used in hospitals. This conventional infusion method has many disadvantages. These disadvantages include still using gravity, an arterial drop rate of ≥ 20%, and a flow rate that is difficult to regulate accurately [4]. Based on this study, the manual infusion model is not appropriate when used for high-alert drug injection.

Bright infusion is an infusion model that works automatically. This method uses an infusion pump. The tool works on the principle of a peristaltic pump to distribute infusion fluids [5]. The infusion pump must be WHO standard with a flow rate accuracy of at least ±5% [6]. Using non-standard infusion pumps results in system failure and the pump working uncontrollably [7]. The following are several failures in the infusion pump working system that were found. Using an infusion pump that is too long can cause heat and slow the rotation speed. Likewise, the condition of the infusion pump is old, which impacts inaccurate dosing. Apart from that, tools that do not comply with the specified test specifications are often found to have non-linearities. Based on the description of the failure of the infusion pump model. several researchers have innovated automatic infusion machines to improve the quality of administering high-alert drugs so that the dosage is correct. [8]. Previous research has been done on the innovation of automatic infusion machines to improve the quality of high-alert drug delivery so that the dose is correct. The working system uses a cuff pressure control system. The cuff is used to press the infusion bottle. The cuff pressure is adjusted based on the drip rate as a control reference. The control used is fuzzy logic control. The results are pretty good, with a precision of 96.75%. However, this design does not comply with the design required by WHO because this design has the potential to cause bubbles in the infusion line so that air enters the intravenous, which can cause death; this incident is called embolism [9]. The application of fuzzy logic for stepper motor speed control shows good results, but it was used for high speeds above 300rpm in this study [10]. The PI control method was chosen because, in several studies, motor controllers showed that PI control was better than PID controllers for control stepper motor [11]. Apart from that, this type of control is also easy to implement and develop for low-speed control of stepper motors because it has been proven to eliminate resonance at low speeds and reduce vibrations at high speeds [12].

Referring to the problems and literature review, this research designs a PI control system for controlling low-speed stepper motors in the range of 0 - 100 RMP to determine the flow rate in infusion machines. This research implements a simulated and actual PI control system on hardware and is verified with a medical-grade standard calibration tool. This research aims to improve the stability and accuracy of the infusion fluid flow rate by looking at the performance results of the PI control system design applied to the infusion pump machine.

2. RESEARCH METHOD

This research aims to create an infusion pump machine based on Arduino nano control in a close loop using PI Control. The tuning method used is the Ziegler Nicholes type 1 method and the Cian Cone method to produce the system transfer function. The results of the PI constant tuning are applied to the Arduino microcontroller so that the microcontroller can work to control the infusion pump machine hardware. System testing takes data in real-time using the IDA analyzer measuring instrument and system simulation using Simulink Matlab. The speed control application on a stepper motor is done by adjusting the frequency of the square wave signal that enters the stepper motor driver; the higher the frequency, the faster the rotation speed will be [13]. In addition, motor speed control is also applied to molding; the control used is PID control. PID control works by regulating the PWM signal input that enters the motor driver to achieve a constant stepper motor speed during the printing process [14].

2.1. Block Diagram and Wiring Diagram of infusion pump

The overall design of the system block diagram is shown in Figure 1. The infusion pump consists of several parts: a keypad to enter the desired set point value, an AS5600 speed sensor, a microcontroller, a TMC2088 motor driver, a Nema 17 stepper motor, and an LCD. The AS5600 sensor is used because it works based on changes in angle, making it possible to read small changes in the stepper motor's rotation. The advantage of this sensor is that it is suitable for important parts in low-speed control of a stepper motor.

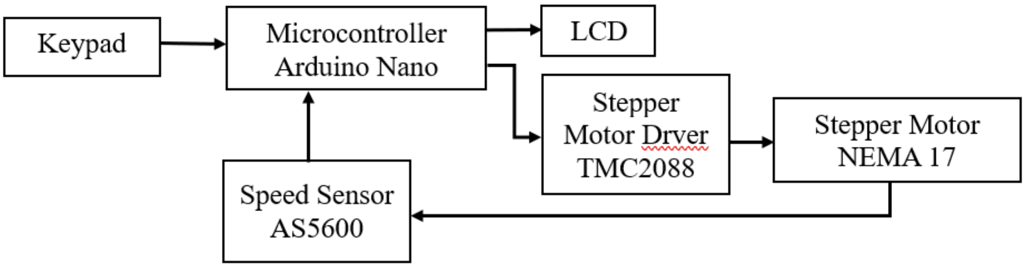

Figure 1. Infusion pump block diagram

A 12V-3A DC power supply provides power to the infusion pump machine. The control center uses an Arduino nano-type microcontroller. Command instructions to determine the desired flow rate and volume of infusion fluid are used using a keypad. Meanwhile, to regulate the flow rate of infusion fluid using a Nema 17 stepper motor and TMC2088 as a motor driver. This infusion pump machine is built in a closed loop system with an AS5600 speed sensor as feedback. The display for monitoring the results of the process uses an LCD screen in digital form. Figure 2 shows a schematic form of an electronic circuit. To read low speeds below 50 rpm, a data smoothing method or average calculation is needed. The data for stable reading requires 200 samplings, and the average data sampling delay is 10ms.

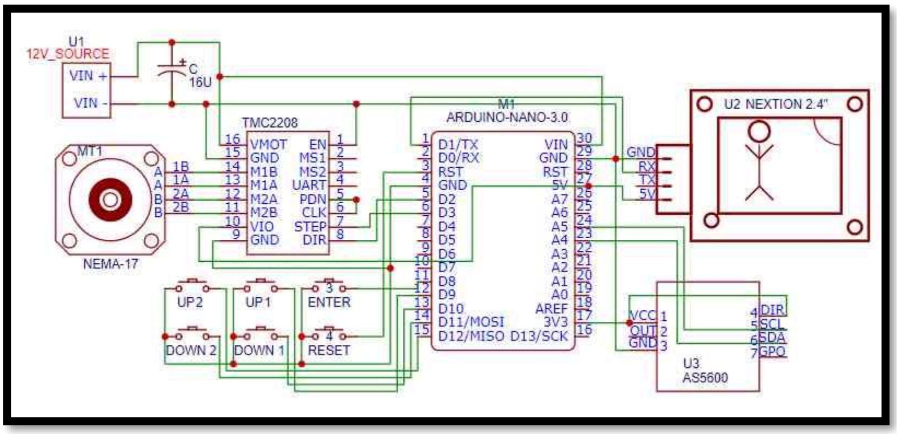

Figure 2. Infusion pump schematic circuit

2.2. Infusion Pump System Mechanical Diagram

The linear peristaltic pump mechanism is used in the proposed design. The main driver is a Nema 17 bipolar stepper motor with a gear ratio of 16:40. The mechanical diagram and physical form of the Pump motor are shown in Figure 3 and Figure 4.

Figure 3. Linear peristaltic pump

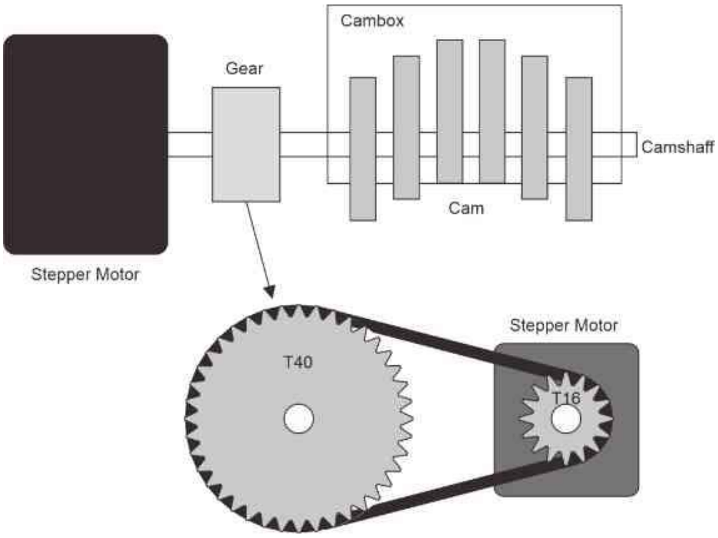

Figure 4. Linear peristaltic pump mechanics

2.3. Convert RPM to ml/h

The method for changing the RPM value to ml/h is done by conducting a trial set point RPM at several points, looking at the flow rate value read on the IDA, and then recording it. The following is a graph of the flow rate against RPM, shown in the Figure 5.

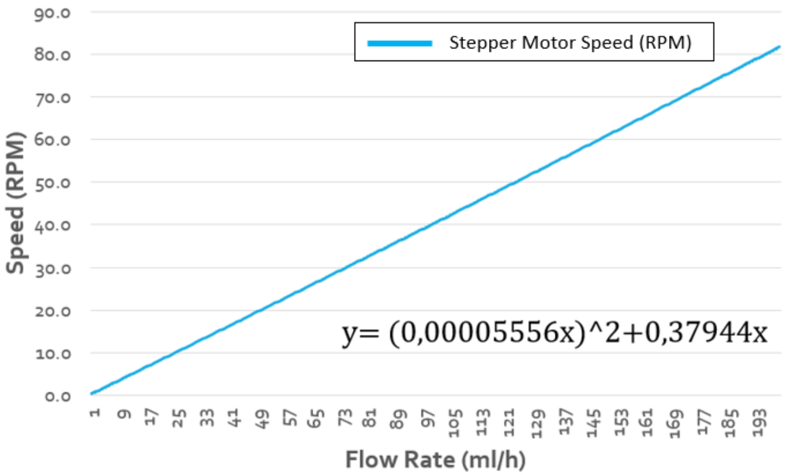

Figure 5. RPM to ml/h conversion graph

2.4. Transfer Function Design

The transfer function of the infusion pump is obtained through experiment. The plant is given an input signal in the form of a step unit in an open loop position, and then the output signal is recorded. The transfer function is obtained using the the Cian cone method [15], using the first-orderthe approach. Transfer function equation (1) is obtained from the result of response graph identification in Figure 6.

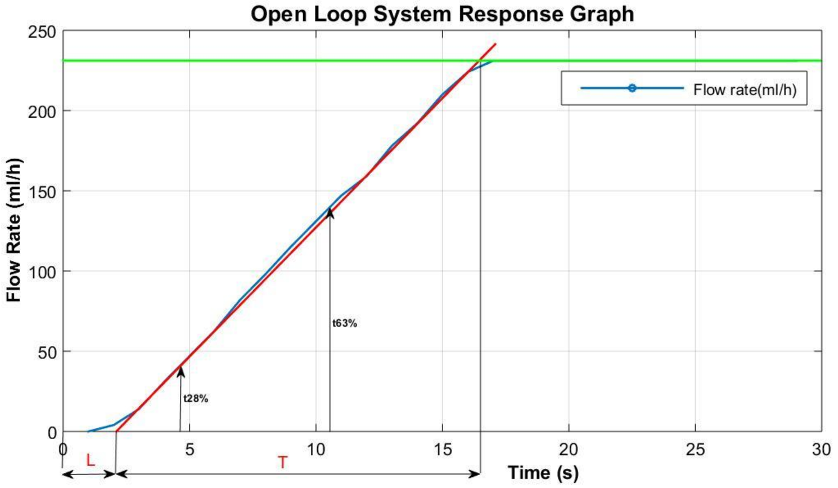

Figure 6. Open loop system response graph

From the image above, it can be seen that the smoothing effect of data causes changes in flow velocity to experience a delay. *L* is the time delay when the flow velocity value begins to increase. *T* is the time delay from the first change in the flow velocity value until the flow velocity begins to experience a stable point. The red line is an aid line to draw the S graph. The green line is the maximum flow rate point that can be achieved.

t28% : 4,76s
t63% : 10,71s
Δ : 231
δ : 231

$$Kp = \frac{\Delta}{\delta} = \frac{231}{231} = 1$$

τ = 1,5 (t63% - t28%)
= 1,5 (10,71 - 4,76)
= 16,065 – 7,14
= 8,925

Θ = t63% - τ
= 10,71 – 8,925
= 1,785

$$\frac{Y(s)}{X(s)} = \frac{Kpe^{-\theta s}}{\tau s + 1}$$

$$= \frac{1e^{-1{,}785s}}{8{,}925s + 1}$$

Transfer function :

$$G(s) = \frac{1}{8{,}925s + 1} \tag{1}$$

The open loop response graph is also used to find the constant values of Kp and Ki using the Ziegler Nichols type 1 method. The following is a calculation to find Kp and Ki:

$$Kp = 0.9\frac{T}{L} = 0.9 \text{ x } \frac{14}{2} = 6.3$$

$$Ti = \frac{L}{0.3} = \frac{2}{0.3} = 6.66$$

$$Ki = \frac{Kp}{Ti} = \frac{6.3}{6.66} = 0.945 \tag{2}$$

3. RESULTS AND DISCUSSION

3.1. PI Control Simulation Result

The system transfer function obtained using the Ciancone method is applied to PI control which is simulated in Simulink, the following is the Simulink block diagram shown in Figure 7 and the response graph is shown in Figure 8.

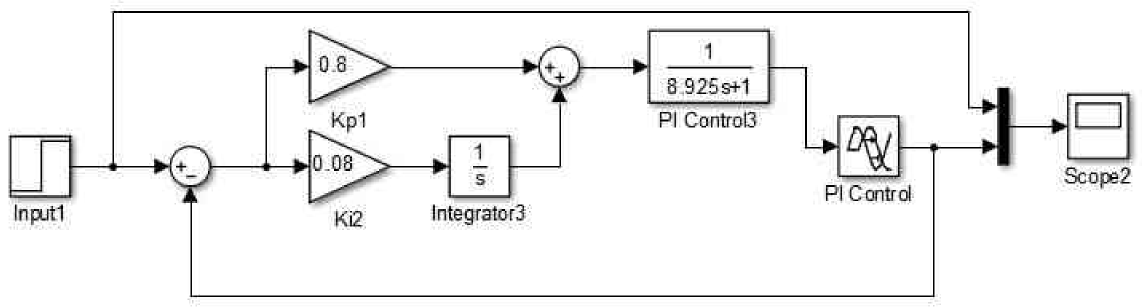

Figure 7. Diagram block simulink simulation

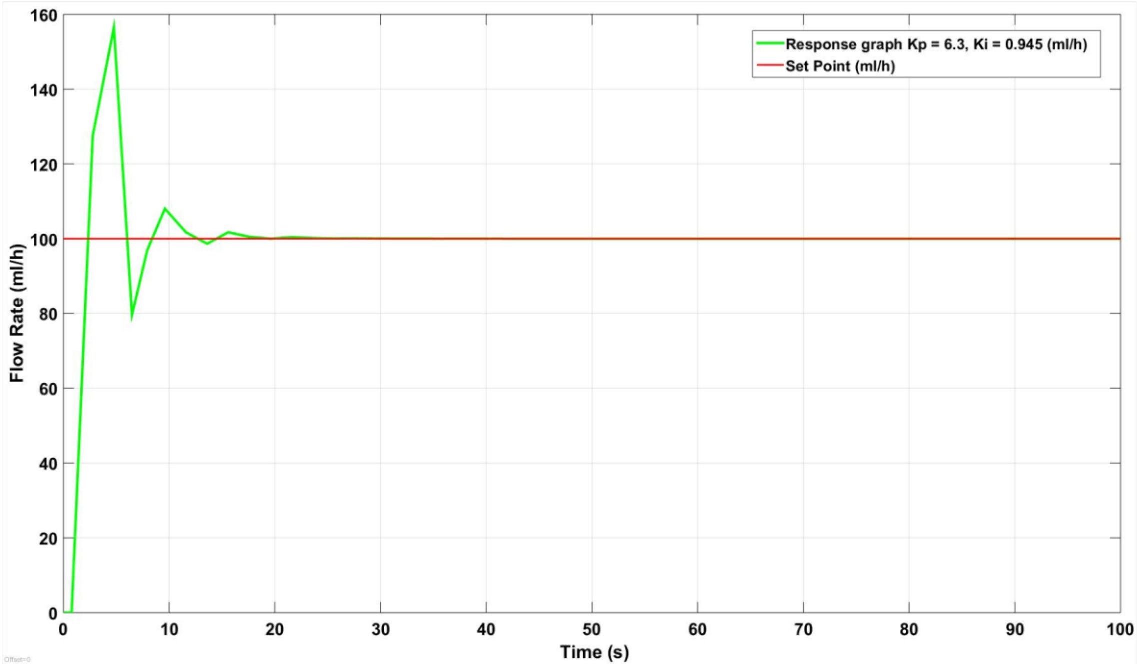

Figure 8. System response graph

A response graph is obtained in the simulation, as shown in Figure 13. The response graph shows that the PI control system with Ziegler Nicholes type 1 tuning constants, namely with Kp = 6.3 and Ki = 0.945, can reach the stability point but still experiences a very high overshot. This is not allowed in the infusion pump working system because overshot occurs, resulting in an excess dose of medication entering the patient. Therefore, adjusting the PI constant with initial adjustments to Kp and Ki from the Ziegler Nicholes tuning results is necessary. Adjustments are made by trial and error, referring to the rules of the PID control system. The following trial error results are shown by the response graph in Figure 9.

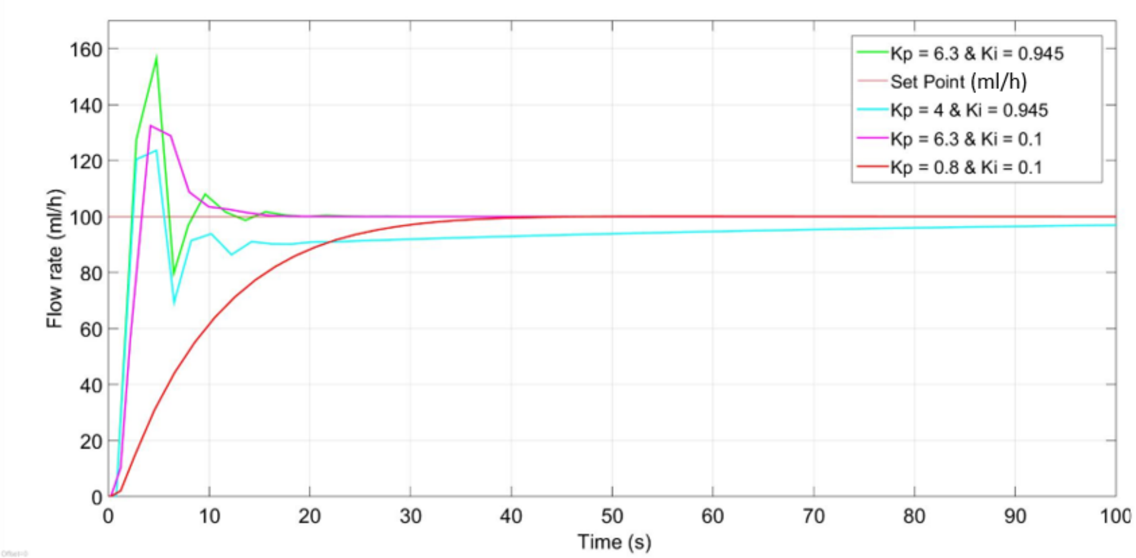

Figure 9. Response graph from adjusting the PI constant

In the trial-error process, a simulation is carried out by increasing and decreasing the Kp and Ki values. So, we get several response graphs. The first experiment was carried out by reducing the Kp value; the resulting impact was that the system experienced an overshoot and did not reach stability. The second experiment reduced the Ki value; the resulting impact was that the overshot decreased but did not wholly eliminate the overshot, and the system achieved stability. The third experiment reduced both values to Kp = 0.8 and Ki = 0.1. It produces pretty good results; for example, the response graph does not experience overshoot and can achieve stability. This system cannot be maximized to the fastest rise time speed except with control modification. Because this system delays sensor reading when focusing on the rise time speed, the simulation and accurate measurement using IDA will not be synchronized. It would be better if the display and real-time IDA measurements were always synchronized with each change. The Kp = 0.8 and Ki = 0.1 is the fastest rise time point and is synchronous between the control system and accurate monitoring of IDA measurements. The following is a detailed response time shown in Table 1.

Table 1. Response time

Kp	Ki	Rise Time (s)	Settling Time (s)	Overshot	Error Steady State (%)
6.3	0.945	1.25	11.50	56.53	0
4	0.945	1.86	12.86	32.50	0
6.3	0.1	1.32	-	-	Not Achieved
0.8	0.1	19.49	32.39	0	0

3.2. Machine Design Results

The following is a manifestation of the results of the tool that was successfully built. The tool is a prototype that has been neatly packaged and quickly set up by the nurse. The overall shape of the tool is shown in Figure 10. Moreover, the electronic part is also shown in Figure 11.

Volume 12, Issue 1, April 2025, pp. 20-30
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v12i1.4541

Figure 10. Infusion pump Prototype results

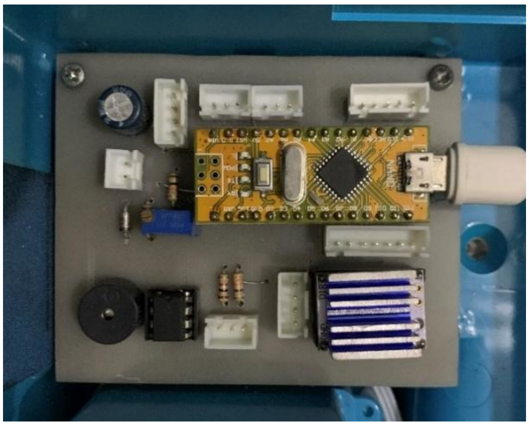

Figure 11. Electronics Board

3.3. Performance Testing

Furthermore, the results of implementing the fuzzy-PI control design on the infusion pump machine were standardized measurements using the Infusion Device Analyzer (IDA) calibration measuring tool. Measurements were performed 5 times with a 10-minute break between each data collection. Figure 18 shows the measurement technique; the results are recorded in Tables 2 and 3.

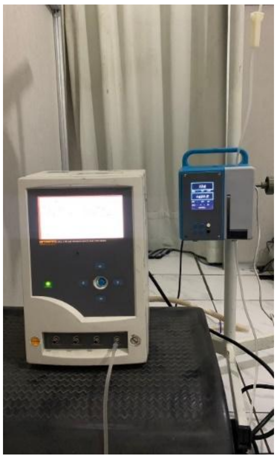

Figure 12. Documentation of Flow rate data collection process using IDA

Table 2. Flow rate measurement results

Set point (ml/h)	Flow rate Tertampil (ml/h)	Flow rate terukur (ml/h)				
		1	2	3	4	5
25	25	25,40	25,46	25,47	25,42	25,43
50	50	50,44	50,48	50,31	50,25	50,31
75	75	75,11	75,07	75,23	75,10	75,23
100	100	100,11	100,01	100,05	100,04	100,04
125	125	125,40	125,37	125,34	125,34	125,33
150	150	150,98	151,09	151,21	151,24	151,27

In Table 6a, the data is obtained by recording the flow rate on the infusion pump display and compared with the actual flow rate measurement using the IDA analyzer in real-time. Actual flow rate data was taken 5 times with a data collection range of 10 minutes. If we observe the tool's performance at each set point, the infusion pump can reach the set point and maintain the flow rate at the set point. This indicates that the PI control system on the infusion pump is working correctly.

Table 3. Results calculation

Mean (ml/h)	correction value (ml/h)	Relative Correction (%)	Max (ml/h)	Min (ml/h)	Accuracy (%)	Stability
25,44	0,44	1,73	25,47	25,40	98,27	0,07
50,36	0,36	0,72	50,48	50,25	99,28	0,23
75,15	0,15	0,20	75,23	75,07	99,80	0,16
100,05	0,05	0,05	100,1	100	99,95	0,1
125,36	0,36	0,28	125,4	125,3	99,72	0,07
151,16	1,16	0,77	151,3	151	99,23	0,29

In table 3, data table 2 is processed to produce numbers used to analyze the system's success, namely accuracy, relative correction, and stability from 5 tests at the target value to be achieved. Relative correction is the correction value to the average value multiplied by 100%. The accuracy of the presentation calculation is obtained from 100 minus the relative correction value. Meanwhile, the stability value is the difference between the maximum data and the minimum data.

From the data obtained, such as accuracy, relative correction, and stability, the Correlative correction obtained with the highest correction percentage permitted by ECRI is 10%. From the data above, the relative correction of measurements at each set of points is only 2%, far below the maximum limit. Accuracy is the ability of a tool to reach a target. If it is closer to the target, it is more accurate. The data above shows that the minimum accuracy is 98.26%, and the maximum accuracy is 99.95%. WHO recommends a maximum specification of ±5% of the set point. Compared with WHO provisions, the tool results show good accuracy—the more excellent the accuracy, the better the tool's performance. In terms of stability level, with a stability value of 0.29 at set point 150 and 0.07 at set point 25, the maximum flow stability allowed is 2 ml/h. This shows good stability.

4. CONCLUSION

From the results obtained, it can be concluded that the PI control system applied to the infusion pump can work well, as proven by simulation results and direct application, and the machine can reach and maintain the flow rate at the set point. It has been proven that the relative correction value obtained is still far from the limit allowed by ECRI, namely 10%. In terms of accuracy, the infusion pump that can be made can reach an accuracy of above 98%, meaning that the greater the accuracy, the infusion pump can enter the drug dose accurately according to the patient's needs and, of course, avoid over-dose and under-dose. In terms of stability, it also shows good results, namely less than 0.3 ml/h, which means it is safe if used for a long time. Modifying the control or combining control methods allows for the optimization of rise time while still paying attention to overshot and real-time flow rate synchronization.

Acknowledgments

Thank you to Mr. Nana, who is my thesis mentor at PNJ. I can establish myself as someone who can pursue the field of control systems.

REFERENCES

[1] Menteri Kesehatan Republik Indonesia, "Standar Pelayanan Kefarmasian Republik Indonesia di Rumah Sakit," Indonesia, 2016.

[2] A. Hasan Basri and A. Taufiq, "Hubungan Tingkat Stress Kerja Perawat IGS Dengan Ketepatan Waktu Pemberian Obat High Alert," *J. Ners Community*, vol. 12, no. 02, pp. 258–267, 2021.

[3] P. Studi and T. Elektromedik, "Efektivitas Penggunaan Infuse Pump Terhadap Pasien," *BALI Heal.*, vol. 2, no. November, p. 69, 2018.

[4] E. Greau *et al.*, "Automatic versus manual changeovers of norepinephrine infusion pumps in critically ill adults: a prospective controlled study," *Ann. Intensive Care*, vol. 5, no. 1, pp. 1–9, Dec. 2015, doi: 10.1186/s13613-015-0083-7.

[5] E. A. Smith and G. Gray, "Developing a Smart Infusion Pump Dedicated to Infusion Safety," *Ergon. Des.*, vol. 30, no. 2, pp. 4–12, 2022, doi: 10.1177/1064804620944760.

[6] World Health Organization, "Technical specifications for infusion devices," in *Technical specifications for infusion devices*, World Health Organization, 2020. [Online]. Available: https://ismp.org

[7] M. Baeckert *et al.*, "Performance of modern syringe infusion pump assemblies at low infusion rates in the perioperative setting," *Br. J. Anaesth.*, vol. 124, no. 2, pp. 173–182, Feb. 2020, doi: 10.1016/j.bja.2019.10.007.

[8] R. T. Yunardi, D. Setiawan, F. Maulina, and T. A. Prijo, "Pengembangan Sistem Kontrol dan Pemantauan Tetesan Cairan Infus Otomatis Berbasis Labview dengan Logika Fuzzy," *J. Teknol. Inf. dan Ilmu Komput.*, vol. 5, no. 4, p. 403, Oct. 2018, doi: 10.25126/jtiik.201854766.

[9] W. Syahputra, "Aspek Klinis dan Tatalaksana Emboli Paru pada Anak," *Ked. N. Med* |, vol. 4, no. 1, pp. 22–29, 2021.

[10] C. Wang and D. Cao, "New sensorless speed control of a hybrid stepper motor based on fuzzy sliding mode observer," *Energies*, vol. 13, no. 18, Sep. 2020, doi: 10.3390/en13184939.

[11] M. S. Zaky, "A self-tuning PI controller for the speed control of electrical motor drives," *Electr. Power Syst. Res.*, vol. 119, pp. 293–303, 2015, doi: 10.1016/j.epsr.2014.10.004.

[12] K. M. Le, H. Van Hoang, and J. W. Jeon, "An Advanced Closed-Loop Control to Improve the Performance of Hybrid Stepper Motors," *IEEE Trans. Power Electron.*, vol. 32, no. 9, pp. 7244–7255, 2017, doi: 10.1109/TPEL.2016.2623341.

[13] B. C. Wibowo and F. Nugraha, "Kendali Kecepatan Motor Stepper Menggunakan Metode Start

– Stop Berbasis PLC," *J. Tek. Elektro dan Komput.*, vol. 10, no. 3, p. 213, 2021, doi: 10.35793/jtek.10.3.2021.35623.

[14] A. A. P. Anggiana, M. Rifa'i, and H. K. Safitri, "Implementasi sistem kontrol penggerak motor stepper pada proses molding microplastic berbasis PID menggunakan PLC," *J. Eltek*, vol. 21, no. 2, pp. 58–67, 2023, doi: 10.33795/eltek.v21i2.2024.

[15] I. Kholis, "Pemodelan Sistem Pengendali PID Dengan Metode Ciancone Berbasis MATLAB Simulink pada Sistem Pressure Process RIG 38-714," *J. Tek. dan Ilmu Komput.*, vol. 06, no. 23, pp. 257–268, 2017.