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Echanced Control System for Syringe Pump Using PID and IoT-Based Flow Rate Monitoring

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ABSTRACT Syringe pump is a life support device that functions to provide drugs in the form of fluids through the vein to the patient's body in a measurable and consistent within a period of time. This research is designed to make the syringe pump more stable, equipped with PCA (Patient Controlled Analgesia) mode, and IoT-based flowrate monitoring. The contribution made by the author is to improve the working system of the syringe pump to be more stable which is equipped with a PCA mode that functions to inject liquid according to the patient's needs, and facilitate remote flowrate monitoring using IoT. In this research, the author uses the PID method to improve the stability of the motor according to the flowrate setting. From the test results that have been done, the flowrate stability of the PID system is quite good in all settings. The resulting rise time is good enough to reach the setpoint, the average occurs in seconds 1-5, the fastest rise time occurs at a flowrate setting of 5 ml / h, which is 1 second and the longest rise time occurs at a flowrate setting of 20 ml / h, which is 5 seconds. The highest overshoot occurs at a flowrate setting of 50 ml/hour with a value of 1.98 ml/hour and the lowest occurs at a flowrate of 5 ml/hour with 0.44 ml/hour. The highest and lowest stability occurs at a flowrate setting of 10 ml/hour, which is 1.5% and 6.5%. In PCA mode, the largest error obtained is around 1% in all settings. IoT-based flowrate monitoring is good, the value displayed on the LCD in real time is sent and displayed on the web. Based on the results of the data that has been obtained, the PID system is still not optimal in controlling the stability of the flowrate so that in the future it is necessary to find a suitable and balanced combination of Kp, Ki, and Kd values.

INDEX TERMS Syringe Pump, Flow Rate, PID, IoT.

I. INTRODUCTION

Hospitals are health facilities that provide various types of medical care and treatment for sick patients and are supported by rooms and medical equipment that are in accordance with the needs of patients. One of the medical equipment that is often used is the syringe pump. Syringe pump is one of the life support tools that functions to provide drugs in the form of fluids through the vein to the patient's body in a measured and consistent manner within a certain period of time[1],[2], [3],[4]–[7]. In patients with critical conditions, intravenous drug administration through infusion is very risky because it requires a very stable flow rate. Dosing errors due to changes in flow rate can cause risky and dangerous clinical effects[8],[9]–[11]. Clinical effects that can occur include overdose, underdose, allergic reactions, or systemic effects that increase toxicity, morbidity, and mortality[12]. In the syringe pump there is a bolus mode which functions as a one-time administration of a large enough dose of medication in a short period of time and usually there is a PCA (Patient Controlled Analgesia) mode which is almost similar to bolus, but in this mode, there is a dose limit and time lag set by the doctor to avoid overdose, usually used for postoperative pain relief[13],[9]–[11], [14]–[16].

In research conducted by Ayu Wulan in 2023 analyzing the stability of the flow rate using PID and non PID systems on DC motors, the system runs quite well, it's just that the results of PID control on DC motors are not optimal in maintaining the stability of the flow rate with an error value of 5.15%, so it is recommended to try using a stepper motor controlled by a PID system[12],[17], [18]. In 2016, Fikri RH et al conducted research on making a syringe pump with a drive motor using a stepper motor. In the study, testing was carried out with a small volume of 1 ml / hour to determine the level of accuracy and accuracy. A value of 96.60% was obtained for accuracy and 99.24% for precision with a real-time time difference and manual calculation of 0.19 seconds which is influenced by the delay set in the Arduino program[19][20]. In 2022, Phisca AR et al conducted research on Iot-based infusion fluid monitoring to facilitate users in monitoring the volume and number of infusion drops. The web used for monitoring is done per minute in real time with a time lag of 10-30 seconds when displaying results that are affected by internet network speed[21],[22], [23]. In the same year, there was also research that discussed the design of syringe pumps by Fivit M and colleagues. In the study using a stepper motor as a syringe pump driver and obtained a fairly good accuracy value of 96.21% of the test results and analysis[24][25], [26]. In research conducted by Tuful Siregar et al in 2020 analyzed the detection of different syringe sizes with a microcontroller on the TE-331 terumo syringe pump tool. This study uses syringe sizes of 10, 20, 30, and 50 ml with measurement parameters, namely resistance and voltage which are carried out 6 times at each measurement point. It was found that the tool can detect different syringe sizes, so that it will minimize errors in drug administration[27]. In a study conducted by Okky FN in 2015 on syringe pumps using the PCA system with bolus elevation of 1-10 ml and a time lag of 1-60 minutes and it can be concluded that the tool runs well according to the elevation that has been done with an average value below 5%[28][4], [29], [30].

Based on the information and literature review used in this research, the authors will conduct research entitled "Motor Round Control System on Syringe Pump Using PID and IoT-Based Flow Rate Monitoring" which aims to complement the shortcomings of previous research to make it easier for users to monitor the flow rate that is running and prioritize the accuracy of the flow rate injected into the patient's body according to the needs equipped with PCA (Patient Controlled Analgesia) mode on the tool.

II. METHODS

This research develops a PID system to control the stability of the motor against the regulated flow rate and is equipped with IoT to monitor the flow rate on the syringe pump. The research method includes several main stages, which are described in detail as follows.

A. BLOCK DIAGRAM

FIGURE 1 On the tool there is an On/Off button that functions to turn the tool on and off. The tool has 2 setting modes, namely infusion mode and PCA mode. If the use only needs to inject the drug slowly, choose infusion mode. When selecting the infusion mode, it will be directed to adjust the volume and flow rate to be given according to the patient's needs. After the adjustment is complete, run the tool by pressing the Start button, the motor will start working to push the syringe tube according to the flow rate that has been set. The optocoupler sensor will work to detect the motor rotation speed and will be forwarded to the ESP32 microcontroller. The PID system will maintain the stability of the motor rotation according to the regulated requirements, if the motor rotation slows down or is faster than it should be, the PID will control the motor to return or stay at the proper rotation speed, so that the liquid released into the patient's body is in accordance with the set flow rate. The volume and flow rate will be displayed on the Nextion TFT LCD screen and the flow rate that is being injected into the patient's body can be monitored through IoT. If the liquid in the syringe tube runs out, the buzzer will sound and the device will stop working. The Stop button is used if an error occurs when the tool is running. If its use requires the patient's role in regulating the incoming dose, it can select PCA mode. When selecting PCA mode will be directed to set the volume and maximum dose, initial loading dose, demand dose, and lockout interval, then press the Start button to run the tool. When the Start button is pressed, the first dose will be injected to the patient and for the next dose must complete the lockout interval or time lag between doses.

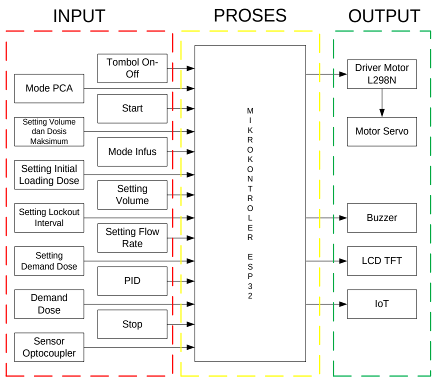

FIGURE 1 Block Diagram Measurement Module

B. *FLOWCHART*

FIGURE 2 When the On button is pressed the LCD screen will turn on and initialize the TFT LCD. If you choose infusion mode, adjust the volume and flow rate and the TFT LCD will display. The Start button is pressed to start injecting the liquid, the motor will work and the optocoupler sensor will work to detect the motor rotation speed and will be forwarded to the ESP32 microcontroller. The PID system functions to maintain the stability of the motor rotation speed so that the liquid released into the patient's body is in accordance with the set flow rate. The number of flow rates that are running can be monitored on IoT. The buzzer will sound when the liquid in the syringe tube runs out and the device will stop working. If an error occurs, you can press the Stop button to stop the tool working. Off button to turn off the tool. If you choose PCA mode, adjust the volume and maximum dose, initial loading dose, demand dose, and lockout interval then press the Start button to run the tool. When the Start button is pressed, the first dose will be injected to the patient and for the next dose must complete the lockout interval or time lag between doses so that if the patient presses the demand dose button in the near future or still in the time lag between doses, the dose will not come out to be injected.

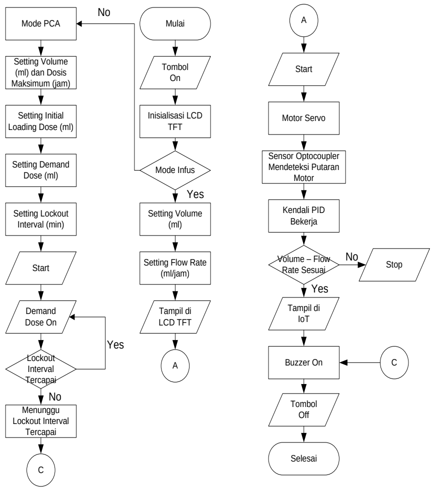

FIGURE 2 Measurement Module Flowchart

C. DATA ANALYSIS

Data analysis uses accuracy calculation to determine the rise time, overshoot, and system stability of the PID parameters used [11].

$$Absolute\ Error = Xmn - Xtn \qquad (1)$$

Explanation :
Xmn : Measured Value
Xtn : Actual Value

$$Relative\ Error = \frac{Xmn - Xtn}{Xtn}\ x\ 100\ \% \qquad (2)$$

Explanation :
Xmn : Measured Value
Xtn : Actual Value

$$Kp \cdot e(t) \qquad (3)$$

Explanation :
Kp = proportional constant
e = error (ideal state - current state)
t = time

$$Ki \int_0^t e\ (T)dT \qquad (4)$$

Explanation :
Ki = integral constant
t = time
e(T) = error at time (T)
T = Integration variable; the value is taken from time zero to t

$$Kd\,\frac{de(t)}{dt} \qquad (5)$$

Explanation :
Kd = Derivative Constant
de = derivative of error
dt = time interval between two different measurements.

III. RESULT

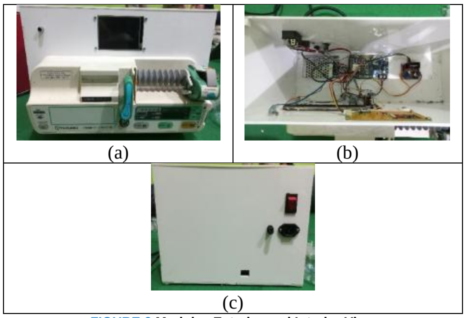

FIGURE 3 Modules Exterior and Interior View

FIGURE 3 (a) shows the front view of the device consisting of a TFT LCD that functions to display the selection of infusion and PCA mode settings, a demand dose button that functions to control the dose involving the patient, and a place to place the syringe. (c) shows the rear view of the device consisting of a power cable and an on/off button to turn the device on and off. (b) shows the inside of the device which consists of Arduino ESP32 as a microcontroller to process the device program, L298N motor driver and servo motor to push the plunger, optocoupler sensor to detect motor rotation, power supply as the voltage source of the device.

TABLE 1
Rise TIme PID and non PID System

Setting Flow rate (ml/jam)	*Rise Time* (second)								
	Non PID	PID							
	I	I	II	III	IV	V	VI	VII	VIII
50	1	3	5	4	4	3	3	3	3
20	1	2	5	5	5	5	5	5	2
10	1	1	3	2	3	2	3	3	3
5	1	1	3	2	2	1	2	1	1

Commented [O1]:

TABLE 1 shows the rise time data on the PID system obtained in 8 experiments and non PID 1 experiment. It can be seen in the PID system rise time with a flow rate setting of 50 ml / hour occurs at seconds 3-5, flow rate 20 ml / hour occurs at seconds 2 and 5, flow rate 10 ml / hour occurs at seconds 1-3, and flow rate 5 ml / hour occurs at seconds 1-3. In the non PID system, the rise time of all settings occurs at second 1.

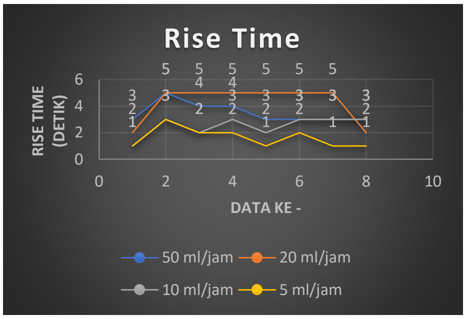

FIGURE 4 **Rise Time PID System**

FIGURE 4 it can be seen the rise time that occurs in the PID system in all flow rate settings in 8 trials. Overall rise time occurs between seconds 1-5. Rise time at a flow rate of 50 ml / h is dominant at second 3, flow rate 20 ml/h at second 5, flow rate 10 ml/h at second 3, and flow rate 5 ml/h at second 1.

TABLE 4
Overshoot PID dan Non PID

Setting Flow rate (ml/jam)	*Overshoot* (ml/jam)								
	Non PID	PID							
	I	I	II	III	IV	V	VI	VII	VIII
50	50.28	51.74	51.84	51.98	51.89	51.94	51.59	51.91	51.39
20	20.17	21.15	21.23	21.13	21.11	21.16	21.2	21.12	21.17
10	10.11	10.58	10.56	10.49	10.56	10.54	10.45	10.55	10.52
5	5.09	5.37	5.43	5.39	5.4	5.36	5.44	5.34	5.43

TABLE 4 shows overshoot data on the PID system obtained in 8 trials and non PID 1 trial. It can be seen in the PID system with 8 trials the highest overshoot with a flow rate setting of 50 ml/hour at 51.98 ml/hour, flow rate of 20 ml/hour at 21.23 ml/hour, flow rate of 10 ml/hour at 10.58 ml/hour, and flow rate of 5 ml/hour at 5.44 ml/hour. In the non PID system, the highest overshoot was at flow rates of 50, 20, 10, and 5 ml/h respectively, namely 50.28; 20.17; 10.11; and 5.09 ml/h.

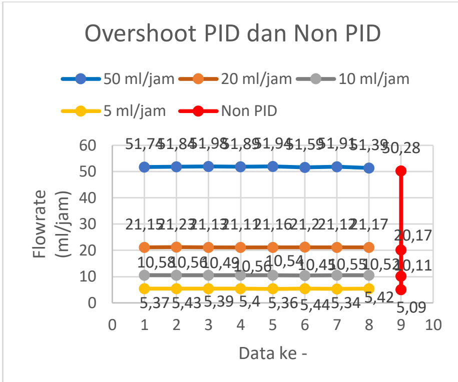

FIGURE 5 **Overshoot PID and non PID System**

FIGURE 5 it can be seen the overshoot that occurs in the PID and non PID systems in all flow rate settings in 8 trials and non PID 1 trial. Overshoot at a flow rate of 50 ml / h with the highest PID system, which is 51.98 ml / h and non PID, which is 50.28 ml / h, flow rate 20 ml / h with the highest PID system, which is 21.23 ml / h and non PID, which is 20.17, flowrate 10 ml / h with the highest PID system, which is 10.58 ml / h and non PID, which is 10.11, and flowrate 5 ml / h with the highest PID system, which is 5.44 and non PID, which is 5.09 ml / hour.

TABLE 5
Stability PID and non PID System

Setting Flow rate (ml/jam)	Stabilitas (ml/jam)								
	Non PID	PID							
	I	I	II	III	IV	V	VI	VII	VIII
50	0.28	1.82	1.84	2.08	2.1	2.04	1.03	1.2	1.03
20	0.17	1.15	1.23	1.2	1.11	1.16	1.03	1.01	1

10	0.11	0.65	0.56	0.49	0.56	0.54	0.57	0.26	0.15
5	0.09	0.57	0.57	0.4	0.47	0.56	0.38	0.15	0.13

TABLE 5 shows stability data on the PID system obtained in 8 trials and non PID 1 trial. It can be seen in the PID system with 8 times the lowest stability experiment at a flow rate setting of 50 ml / hour about 2.1 ml / hour or 4.2% and non PID 0.28 ml / hour or 0.56%, flow rate 20 ml / hour about 1.23 ml / hour or 6, 15% and non PID 0.17 ml/hour or 0.85%, flow rate 10 ml/hour about 0.65 ml/hour or 6.5% and non PID 0.11 ml/hour or 1.1%, flow rate 5 ml/hour about 0.57 ml/hour or 11.4% and non PID 0.09 ml/hour or 1.8%.

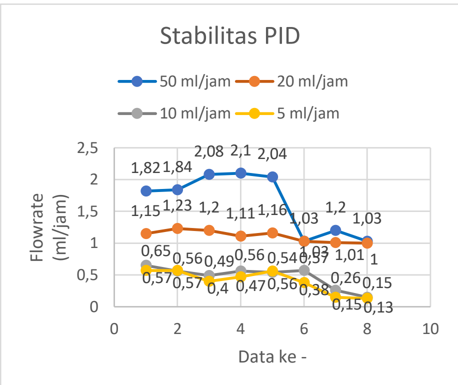

FIGURE 6 Stability PID System

FIGURE 6 it can be seen the stability that occurs in the PID system in all flow rate settings in 8 trials. The best stability is at a flow rate of 50 ml/hour, which is 1.03 ml/hour, a flow rate of 20 ml/hour, which is 1 ml/hour, a flow rate of 10 ml/hour, which is 0.15 ml/hour, and a flow rate of 5 ml/hour with, which is 0.13 ml/hour.

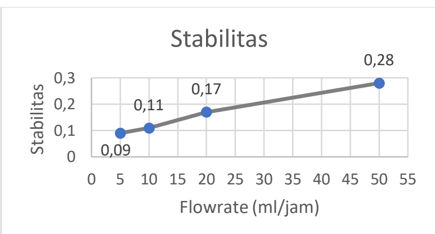

FIGURE 7 Stability non PID System

FIGURE 7 it can be seen the stability that occurs in the non PID system in all flow rate settings in 1 experiment. The best stability occurs at a flow rate of 5 ml/hour, which is 0.09 ml/hour and the worst at a flow rate of 50 ml/hour.

IV. DISCUSSION

The results of the tool test that has been carried out using the IDA calibrator. Overall the stability of the flow rate is quite good in all settings, the rise time value can be said to be good because the system can quickly rise to approach the setpoint value around 90% of the setpoint with an average time of 1-5 seconds although in the experiment there are still some whose rise time exceeds the setpoint. Overshoot on the highest system occurs at setting a flow rate of 50 ml / hour, which is 1.98 ml / hour and the lowest at a flow rate of 5 ml / hour, which is 0.44 ml / hour. The highest stability at a flow rate setting of 50 ml/hour is about 2.1 ml/hour or 4.2%. When the PID data above shows that the PID system has been running quite well because the value of rise time, overshoot, and stability is still within the tolerance value, which is 5%, although in some experiments there are still values that are not good enough. This can occur because the motor used is stable so that when the PID system is applied it is a little difficult to find the appropriate PID value, so it still results in overshoot or errors that are quite high in some settings.

The results of the device test that has been carried out using the IDA calibrator. The stability of the flow rate in the non PID system is very good and close to the set setpoint and the value obtained is quite stable, although there is still a difference in value. The non PID system does not need a long time to approach and reach the setpoint occurs in the first second. Overshoot that occurs is also very small, the highest value of overshoot that occurs at a flowrate of 50 ml / hour, which is 0.28 ml / hour and the lowest at a flow rate of 5 ml / hour, which is 0.09 ml / hour. For stability is also very good, the best stability occurs at a flow rate setting of 5 ml / hour, which is 0.09 ml / hour and the worst at a flow rate of 50 ml / hour, which is 0.28 ml / hour. This can occur because it uses a servo motor that is already stable from the default tool, so that adjustments to the non-PID system are not so difficult.

From the data obtained, the overall application of IoT can run well for real-time monitoring that can be viewed via the web. The value displayed on the LCD will also be immediately sent and displayed on the web in real time, so there is no data loss. It's just that the tool is very dependent on wifi when used, because the tool can only run when connected to wifi, both for setting up and starting the tool. Meanwhile, when connected to a wifi whose network is poor, it will cause the tool to lag or delay when setting up and starting the tool.

V. CONCLUSION

In this study, a syringe pump tool has been made that has an infusion mode with volume and flow rate parameters with a PID system and PCA mode with initial loading dose, demand dose, and lockout interval parameters equipped with monitoring using IoT. From the test results, the following conclusions are obtained, namely; Design of servo motor stability on syringe pump with PID control. The control parameter values used are Kp 2.5; Ki 0.07; and Kd 0.15. The resulting rise time is quite good and fast when approaching or reaching the average setpoint occurs in seconds 1-5, the fastest rise time occurs at a flow rate setting of 5 ml / hour, which is 1 second and the longest rise time occurs at a flow rate setting of 20 ml / hour, which is 5 seconds. The highest overshoot occurred at a flow rate setting of 50 ml/hour with a value of 1.98 ml/hour and the lowest occurred at a flow rate of 5 ml/hour with 0.44 ml/hour. The highest and lowest stability occurs at a flow rate setting of 10 ml/hour, which is 1.5% and 6.5%. The syringe pump design is equipped with PCA (Patient Controlled Analgesia) mode with the largest error obtained around 1% for both the initial loading dose, lockout interval, and demand dose settings. The proposed method can perform IoT-based flowrate monitoring well, the value displayed on the LCD in real time is immediately sent and displayed on the web. From the above statements, it can be concluded as a whole, that the module made in this study produces good results and is close to what the author expects.

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