Variable Infusion Rate Syringe Pump Design with Computerized System

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February 17, 2023

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Abstract— **Syringe infusion pumps are devices that deliver a small amount of fluid to a patient over long periods. There are different ways of infusing a liquid and the parameters to define the infusion rate are determined by the operator. However, the delay in the continuous release of a fluid at low infusion rates (1mL/h) is a clinical problem, because it can cause a lack of a certain drug, interfering with the treatment of diseases and the patient's physiological stability. In addition, the precipitation of drug release can cause overdose. Therefore, the objective of this study is to design and develop a syringe infusion pump that achieves low infusion rates precisely, with a computerized control system.**

Keywords— **Syringe pump, infusion rate, computerized system.**

I. Introduction

Infusion pumps are devices that deliver a specific amount of fluids in a certain period to a patient in clinical, hospital and home environments [1,2]. There are several types of infusion pumps commercially, those in syringes are used in clinical environments and for scientific studies, since they administer small amounts of fluid precisely for a relatively long period [6].

The infusion rate has different periods, fast, slow, and continuous or intermittent, as function of the motor speed, define by the waveform period [9]. Each period has a corresponding infusion rate known to the healthcare professional [2,9].

A well-known clinical problem is the delay in the continuous release of fluids, especially at low infusion rates (1 mL/h). This delay is attributed to motor driver start-up, assembly compliance, and mechanical clearances in the syringe fitting [11].

Therefore, the development of a syringe infusion pump with a small, variable and accurate infusion rate is important for the clinical environment and research advancement. In view of this, the purpose of the present paper was to design and develop a syringe infusion pump that achieves low infusion rates precisely, with a computerized control system.

II. Material and methods

A. Mechanical design

The mechanical design was based on a compression system, using an EM-286 Shimano STH-39H112-06 stepper motor recovered from an old EPSON FX880 printer, NEMA17 format, bipolar characteristic, two 33-teeth and 71-teeth gears and a TR8 spindle.

The drive gear (33-teeth) was attached to the stepper motor axis and the driven gear (71 teeth) was linked to the spindle. The use of gears was necessary to decrease the speed and increase the spindle rotation accuracy. For this reason the transmission ratio between these gears was calculated. The variables n1 and n2 refer to the RPM (rotation per minute) of drive and driven gears, Z1 and Z2 to the amount of teeth of drive and driven gears, respectively.

$$\frac{n1}{n2} = \frac{Z2}{Z1}$$

$$\frac{n1}{n2} = \frac{71}{33}$$

$$71 * n2 = 33 * n1$$

$$n2 = \frac{33}{71} * n1$$

$$n2 = 0.4648 * n1$$

Therefore, the driven gear has less than half RPM as the drive gear.

The device's structure was designed in 3D modeling by the SolidWorks program, which is a 3D CAD (Computer-Aided Design) software based on parametric computation, creating three-dimensional shapes from 2D geometric operations [13].

With this, the infusion pump body and a base for the electromechanical system were designed (Fig.1). Then, in order to avoid the accumulation of dust and residues that could interfere with the functioning of the gears, a top corresponding to the electromechanical part was designed.

As the operation of the infusion pump is based on a compression system in syringes, a compression bar was designed with a nut fixed in the center, compatible with the spindle and two bearings at the ends. So that the movement of the compression bar remains straight, two linear axes in the body of the equipment compatible with the bearings were implemented.

The last sketch was an adapter to fit smaller syringes.

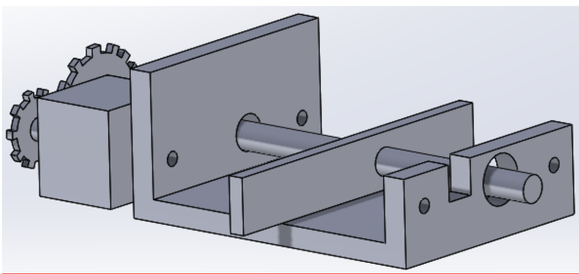

Fig. 1. Infusion pump in 3D CAD.

B. Infusion rate conversion

For the flow conversion, four transfer functions of four syringes were calculated (20 mL, 10 mL, 5 mL e 3 mL), for which the 27G scalp connected to the syringes was taken into account.

For that, each syringe was pressed by the equipment at times of 700ms, 800ms, 900ms and 1000ms until a subunit was reached and the number of steps exerted by the motor were simultaneously enumerated.

Then the flow rate was calculated per mL/step, then the flow rate was converted to mL/s and finally remodeled to mL/h.

The transfer functions were composed by the time between steps (t) as a function of the flow rate (u) determined by the applicator.

The 20 mL transfer function:

$$t = 1.6812 - (0.9841 * u)$$

The 10 mL transfer function:

$$t = 1.6812 - (0.1669 * u)$$

The 5 mL transfer function:

$$t = 1.6812 - (0.2528 * u)$$

The 3 mL transfer function:

$$t = 1.6812 - (0.3956 * u)$$

C. Eletronic circuit

For the development of the electrical circuit, the Arduino Mega microcontroller was used because it has regular processing, 54 digital pins and 256 KB of flash memory [4].

An H-L298N driver was also used to control the stepper motor. The electrical circuit consists of the motor connected to the driver through the OUT1, OUT2, OUT3 and OUT4 ports and the IN1, IN2, IN3 and IN4 ports of the driver connected to pins 8, 9, 10 and 11 of the Arduino. Finally, an external 12V source was used to supply the energy necessary for the motor to run.

D. Embedded system

The Arduino embedded program is responsible for controlling the excitation of the stepper motor coils (Table 1). That said, for the axis to rotate to the right there is an order of excitation of the coils and for the motor to rotate to the left, this order is reversed. The four stages of coil excitation were defined as Case 1, 2, 3 and 4 and Case 5 without coil excitation.

Table 1 Coil excitation order

	Coil A	Coil B	Coil C	Coil D	Axis state
Case 1	1	0	0	0	Step 1
Case 2	0	1	0	0	Step 2
Case 3	0	0	1	0	Step 3
Case 4	0	0	0	1	Step 4
Case 5	0	0	0	0	Stop

The motor speed was defined as a function of time, in ms, between each Case, that is, smaller values of time lead to high motor speed and larger values of time to lower speeds.

Once the syringe used is informed, the algorithm determines the time between steps through the established transfer function. Then, the value of the flow in mL/h is determined by the operator so that the algorithm calculates the value of t, ms, and finally, excites the coil.

E. Dashboard development

The dashboard was designed using Matlab software (license 40686582) because it is a programming platform developed for engineers and scientists based on high-level language and an interactive environment for numerical computation, visualization and programming [5].

The graphical interface consists of a single tab where it will be possible to establish serial communication, determine the syringe used and choose the infusion pump flow rate in mL/h. It will also be possible to immediately stop the procedure and return the compression bar.

F. Validation test

Repetition testing using four syringes (20 mL, 10 mL, 5 mL and 3 mL) at four different flow rates were carried out to assess the accuracy of the infusion rate. In this way, it is possible to evaluate the program's accuracy in achieving the desired flow.

Finally, for data analysis, the percentage error, standard deviation, coefficient of determination and correlation coefficient were calculated.

III. Results

The printed parts and protective caps accommodated the equipment's electromechanics system. However, the body and the compression bar, when manufactured with PLA, showed sensitivity to the compression of the syringe, resulting in the buckling of the parts and destabilizing the dripping of the liquid. So, to eliminate this disturbance, these pieces were made of plywood because it is a stiffer material, and then they were painted black (Fig.2). The fitting of the syringes in both the equipment body and the compression bar has no gaps.

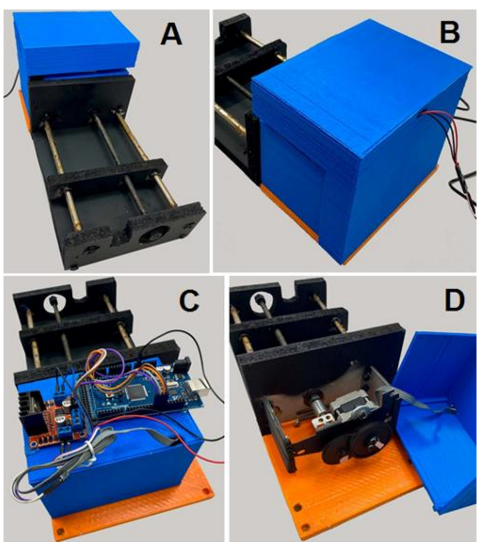

Fig. 2. Infusion pump developed. A) Equipment base and structure; B) Rear part of the equipment; C) Electrical part of the system; D) Mechanical part of the system.

The results of the flow accuracy test were presented in Figure 3. The values between the actual flow and the desired flow were significantly similar. On average, the percentage error was 1.0% and the standard deviation was 0.016.

The lowest infusion rate achieved by the device was 0.71 mL/h and the highest was 5.94 mL/h. There were no delays in starting the motor or significant resistance in the mechanical part.

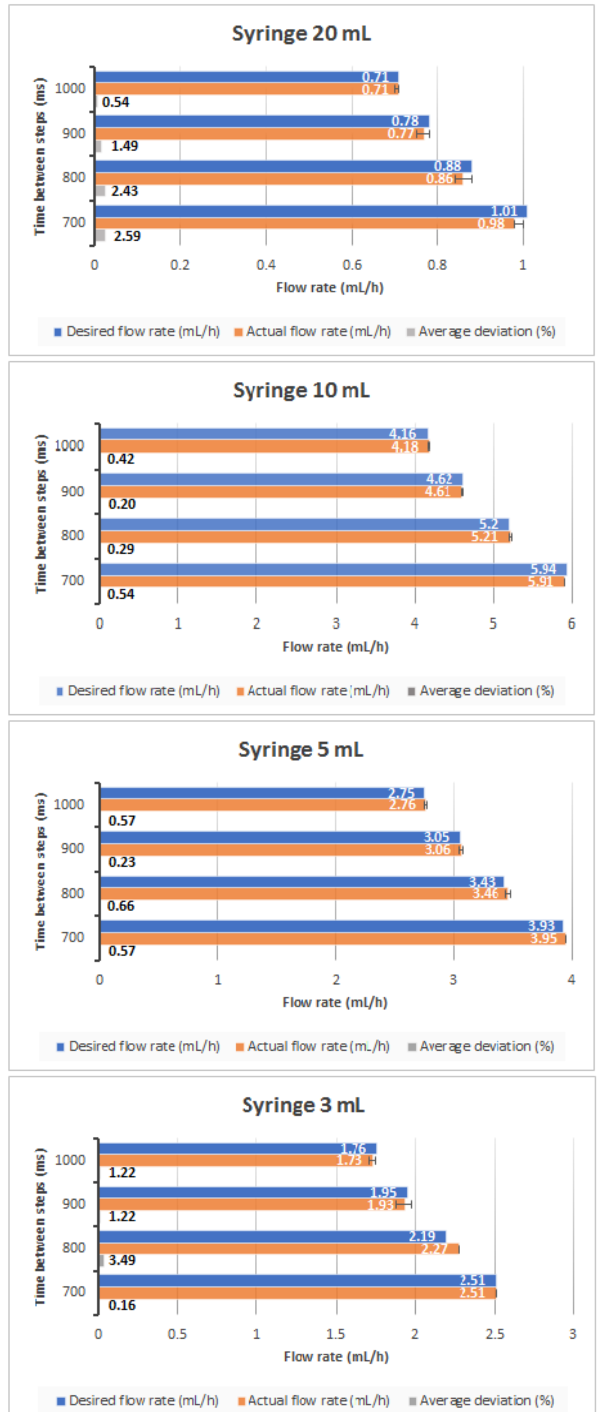

Fig. 3. Validation test results

The dashboard (Fig.4) developed to control the infusion pump contains only one tab, where it is possible to establish serial communication, select the syringe used, determine the desired flow, start or stop the infusion and, at the end of the procedure, return the compression bar. The graphical interface interacted perfectly with the developed infusion pump.

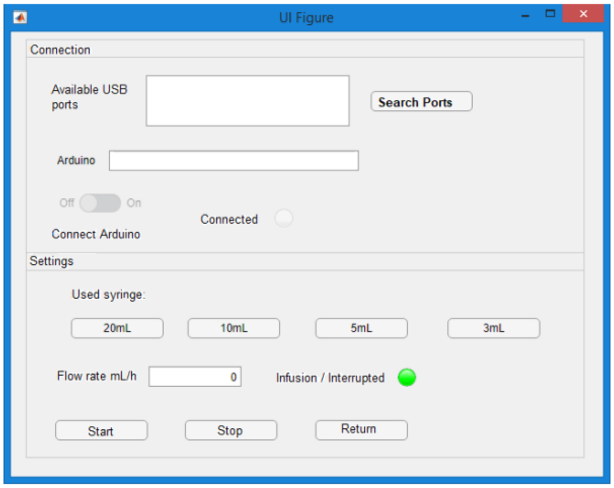

Fig. 4. Infusion pump dashboard

IV. Discussion

The proposed device was developed to allocate one syringe per procedure, in line with study [9] who also designed an infusion pump with these parameters. However, the created device [9] did not allow the choice of syringe size, this problem was solved in the present study, since the operator can select between four syringe sizes (20 mL, 10 mL, 5 mL and 3 mL).

In this same pump [9], the configuration of parameters was performed analog in the device body itself, but this type of system has some limitations related to the management of infusion pump data. In the present study, a synchronous dashboard was created between the computer and the infusion pump, where a serial communication is established and the adjustment of the parameters of each syringe is allowed.

In all tested syringes, the correlation coefficient was very close to 1 (ranging between 0.992 and 0.999), which justifies that the values of the desired and actual flow have a strong and positive association with each other.

In this paper, the mean value of the standard deviation for the 20 mL and 10 mL syringes was 1.25%, for the 5 mL syringe it was 1.5% and for the 3 mL syringe it was 2.25%. According to the study [12] the infusion pump must respond to the average deviation criterion of ±5%, and the syringe pump developed by them had an average deviation of 2.41%. In view of this, the device developed in the present study not only corresponded to the deviation criterion of ±5%, but also reached lower values than the developed pump [6], which proves that the accuracy of the proposed device is better.

Previously published articles [3] and [10] report that the compression syringe mechanism generates high precision continuous flow, with an average error of less than 2%. In the present study, the mean error value for 20 mL syringes was 1.76%, for 10 mL syringes it was 0.36%, for 5 mL it was 0.50% and for 3 mL was 1.52%, showing that the values reached were less than 2%. This was possible because the compression system in the device uses two gears to decrease the spindle rotation speed and increase the compression bar extension. Thus, the proposed device was able to achieve low infusion rates, less than 1 mL/h, without delay in the continuous release of the fluid.

Researchers [8] developed an infusion pump where the maximum error (%) found by them was 4.68% and the minimum of 2.37%, with that, they approach that this type of inconsistency can happen due to mechanical clearance , power supply error, calibration error and loose contact in the motor drive circuit.

Following this pattern, the infusion pump in the present study presented a maximum error (%) of 3.5% and a minimum of 0.2% (approximately), with errors smaller than the results found by the aforementioned researchers. Therefore, this corroborates that the mechanical design of the infusion pump developed operates satisfactorily.

The infusion pump developed by the researchers [7] was designed for 60 mL syringe only and achieved infusion rates between 0.67 mL/h to 5.76 mL/h. While the infusion pump proposed in the present study allowed the use of four syringes and managed to reach infusion rates between 0.71 mL/h and 5.9 mL/h, similar to the aforementioned study.

According to [6], the accuracy of ±5% in the infusion rate is completely satisfactory for clinical use, and the biggest error found in the proposed device was 3.5% in the 3mL syringe, therefore the infusion pump developed corresponded to this parameter.

V. Conclusions

The syringe pump proposed in this article achieved variable flow rates and kept the infusion rate constant with satisfactory precision. The dashboard served its purpose of communicating with the serial and controlling the speed of the motor corresponding to the flow rate of each syringe.

Therefore, the proposed device can be used in clinical and research environments. However, it is necessary to add a security system to the equipment.

ACKNOWLEDGMENT

This work was financially supported by São Paulo Research Foundation (FAPESP, #2017/16292-1) and UMC.

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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