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Developing a Low-Cost Syringe Pump as a Support System for Electrospinning

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ABSTRACT — Electrospinning is one of the techniques used to fabricate nanofibers. The syringe pump is one of the main parts of electrospinning, responsible for injecting the solution into the chamber with high precision. The syringe pump has a simple operating system, but it has a high price on the market. Its high price has been one of the obstacles for research groups in the fabrication of nanofibers. Hence, this research aimed to solve the problem of expensive syringe pumps by developing a low-cost syringe pump using affordable components. This research utilized methods from a literature study of syringe pump design, including the manufacturing and assembly of both hardware and software components. It also involved testing the calibration, optimization, and performance of the syringe pumps. An analysis of each stage was carried out until a conclusion was obtained. This syringe pump built in this research used a NEMA 17 stepper motor and TB6600 motor driver to control the flow rate. The total cost to develop this low-cost syringe pump was IDR632,300. Test and calibration were measured at a flow rate ranging from 1 mL/h to 5 mL/h using distilled water, resulting in an accuracy value of 96.7% and a precision value of 95.0%. Further research should utilize gear wheels to reduce the load of the motor stepper so as to prevent prolonged heated conditions. The results of this research can also be used as insight for researchers to develop another low-cost tool in other research fields.

KEYWORDS — Electrospinning, Flow Rate, Low-Cost Syringe Pump, Nanofibers.

I. INTRODUCTION

Electrospinning is one of the most cost-effective and possible ways to control morphology and a simple and flexible technique for nanofiber production (1D) [1]. The working principle of electrospinning is to provide an electric charge beam to a solution or liquid [2]. Basic electrospinning consists of a high-voltage power supply, a spinneret (jet), and a grounded collector [3]. In the electrospinning process, many parameters can affect the results of electrospinning. These parameters are divided into three, namely, solution parameters, environmental parameters, and process parameters [4]. The process parameters consist of several parameters that affect the nanofiber morphology: voltage value, distance of needle tip to collector [5], and flow rate [6]. Flow rate affects the formation of the resulting nanostructure. When the flow rate is too low, the Taylor cone will not form, causing the spinneret to harden [7]. However, when the flow rate is too fast in the electrospinning process, it will cause the structure to change into particles [8].

The syringe pump is one of the most important parts of electrospinning. It is employed to inject the solution into the electrospinning chamber. The syringe pump pushes the syringe rod with a stepper motor to remove the solution [9]. Nevertheless, the syringe pump is expensive, which makes it an obstacle for the research group focusing on nanofibers using electrospinning. Therefore, developing this low-cost syringe pump allows researchers with limited budgets to conduct research using a syringe pump. Then, they can also allocate the remaining research budget to other academic research requirements. Meanwhile, for the syringe pump manufacturing industry, a low-cost syringe pump can increase syringe pump production. With lower production costs, more products can be produced at the same or even lower prices, broadening the target consumers.

Several studies have been conducted to develop low-cost syringe pumps. A low-cost syringe pump was developed with a total cost of USD75 or IDR1,206,000 [10]. Low-cost syringe pumps that cost less than USD75 [11] and €70 or IDR1,145,550 were also successfully developed [12]. However, these previously developed syringe pumps do not have a volume stop feature. This feature helps set the syringe pump to stop operating when it reaches the volume of the solution set. Therefore, this study developed a low-cost syringe pump incorporating features such as volume controller and flow rate at much reduced cost. The low-cost syringe pump in this research was designed using a NEMA 17 stepper motor and TB6600 motor driver with a 1–5 mL/h flow rate. The developed tool can address the problem of the high cost of the syringe pump without reducing its primary function in the electrospinning process.

II. ELECTROSPINNING PARAMETERS

Electrospinning is a technique of spinning fibers using electrostatic force. Furthermore, it is a technique of spinning a polymer solution using a high-potential electric field to produce fine fibers with a small diameter. The average diameter of fibers produced is about 100 nm–500 nm, where fibers of this size are known as nanofibers [13]. The electrospinning process uses a solution put into a syringe with a metal needle, injected through a spinneret hole (jet) with a small tip, and pulled with a high-voltage electric field. Due to surface tension, the solution at the tip of the needle will be attracted by the electric field and form a droplet/jet. The jet moves towards the collector, which will collect the nanofibers in this section.

The advantages of electrospinning are the easy process, the ability to control morphology, uniformity, and porosity, and the fact that it produces long enough nanofibers [14], [15]. In addition, this technique has the consistency to produce polymer fibers with nanometer to micrometer diameters according to the type of polymer used. The electrospinning technique can produce nanofibers with the smallest size range of about 0.04–2 mm [16]. However, this technique has certain disadvantages, including its relatively unstable product consistency and many parameters [17].

The equipment needed for electrospinning is simple: a high-voltage source, polymer solution, syringe pump, and an aluminum collector with adjustable screen shape (for example, in the form of a rotating drum) [3]. The electrically charged polymer solution is put into a syringe. Next, it is placed on the syringe pump. The electrospinning process begins by applying a high voltage to produce a jet of polymer solution at the syringe pump. The burst of polymer solution under the influence of the electric field will be accelerated towards the electrode with the opposite charge towards the collector screen. The polymer solvent will evaporate, then only the polymer fibers stick to the collector screen [18]. The fibers can have varying sizes as needed.

The quality of electrospinning process results depends on several parameters, including solution, environmental, and process parameters. In electrospinning, the morphology and size of the nanofiber are highly dependent on the process parameters. These process parameters include collector distance, voltage, and flow rate [19].

A. COLLECTOR DISTANCE

The evaporation rate influences the morphological shape of the nanofiber. In the electrospinning process, the evaporation rate is influenced by distance and electric field strength. The greater the distance and the stronger the electric field, the higher the evaporation rate. In the electrospinning process, this spacing should be appropriate to allow sufficient time for the solvent to evaporate before reaching the collector [20]. The distance between the collector and the tip of the needle affects the diameter of the polymer produced. When the distance given is greater, the diameter produced is smaller because the evaporation rate becomes fast, so what sticks to the collector is in the form of wet droplets [21].

B. VOLTAGE

The high voltage applied to the tip of the injection needle generates an electric field in the solution that causes electrostatic forces. The magnitude of the electric field will affect the formation of the Taylor cone. When the voltage is low, the cone volume at the tip of the injection becomes large because the electric field is not strong enough to attract it to the collector. Meanwhile, when the voltage is increased, the solution will be attracted towards the collector [22]. Voltage can affect the morphology and size of nanofiber; when the applied voltage is too high or weak, the electrospinning will result in particles or beads.

C. FLOW RATE

The solution flow rate is a parameter in nanofiber formation. The flow rate can be adjusted using a syringe pump. If the flow rate is too large, the solution at the tip of the needle will drip. Another possibility is that when the voltage is stable, the fibers produced in the collector will become wet [23]. Meanwhile, when the flow rate is too low with a stable voltage, the Taylor cone at the tip of the needle cannot be formed [24].

A high flow rate will enlarge the fibers diameter and particle morphology in the electrospinning process. Due to the high flow rate, more solutions will be released, which can prolong the drying process [25]. The flow rate in the electrospinning process can be adjusted using a syringe pump. The flow rate calculation in the syringe pump is based on (1).

$$Q = vA \tag{1}$$

where Q is the flow rate, v is the flow velocity (m/s), and A is the cross-sectional area (m^2) [26]. Equation (1) can be written as (2).

$$Q = \frac{V}{t} \tag{2}$$

where Q is the flow rate, V is the volume (m^3), and t is the time (s).

A syringe pump is a tool that drives polymer solution in syringe [11]. This tool also controls the amount and rate of polymer solution on a scale of milliliters (mL) to microliters (µL) per minute [27]. The syringe pump can be set to operate at a certain rate using the controller. It can also be adjusted to move right or left as needed. In the electrospinning process, there is usually a syringe pump with a standard capacity of 5 mL. Previous research used several types of syringe sizes, one of which used 5 mL [28].

A syringe pump has high accuracy and is often used in the medical or health field as a controller for dosing infusion fluids to patients. This tool will not cause dosing errors because it can be adjusted as needed. In addition, the syringe pump can also be applied in the field of research, especially in electrospinning and electrospray research.

A syringe pump can be made by using drat axles and bearings to minimize slip and friction when rotating. In addition, it can be designed with the help of a microcontroller as a work control system of the syringe pump. Microcontrollers that can be used include Arduino UNO [27]. Usually, syringe pumps are designed to be in a conditioned room and placed separately from the controller. Syringe pumps have the advantage of high precision and accuracy in injecting volume solution. On the other hand, with such a simple working principle, the price of the syringe pump in the market is very high. In New Zealand, for instance, syringe pump prices reach USD4,400 until USD6,250 [10].

III. METHODOLOGY

A. TOOLS AND MATERIALS

A syringe pump uses several components, from the tool design stage to data validation. In this research, software and hardware were used. Tools and materials used to manufacture syringe pump hardware are shown in Table I. The total cost required for this research was compared with those of previous research. The block of the electronic circuit is shown in Figure 1. TB6600 motor driver, NEMA 17 stepper motor, and Arduino UNO are important components in making a low-cost syringe pump.

1) TB6600 MOTOR DRIVER

TB6600 motor driver is one of the motor drivers that functions as a motion regulator of an electronic circuit, especially to regulate direction and speed [29]. It can be used to regulate the speed response of stepper motors [30]. This

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TABLE I
TOOLS AND MATERIALS

No	Name	Qty	Price (IDR)
1	TB6600 module driver motor	1	73,500
2	NEMA 17 stepper motor	1	87,500
3	Arduino UNO	1	120,000
4	Keypad matrix 4×4	1	27,500
5	LCD I2C	1	37,000
6	Arduino IDE software	1	Open Source (free)
7	Jumper wire	4 packs	40,000
8	Flexible coupling	1	20,000
9	Heat sink	1	10,000
10	Linear shaft	1	6,800
11	Screw	1	10,000
12	Body syringe pump (3D print)	3	200,000
Total			632,300

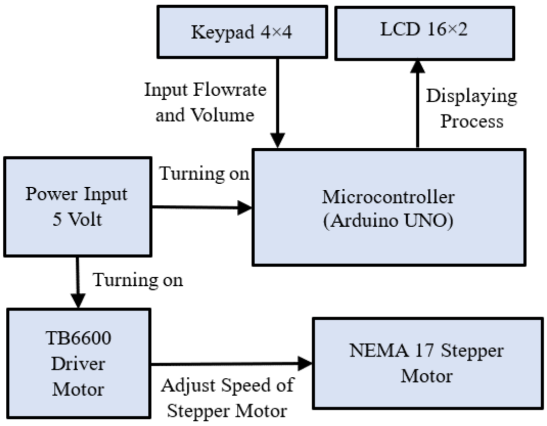

Figure 1. Block diagram of the electronic circuit.

research used the TB6600 as a motor driver because it is suitable for bipolar stepper motors of NEMA 17 and has six micro-step regulator switches covering 1/1, 1/2, 1/4, 1/8, 1/16 and 1/32. This feature is needed to adjust the step at NEMA 17 [29].

2) NEMA 17 STEPPER MOTOR

This research used the NEMA 17 stepper motor, a type of bipolar motor with a step angle of 1.8°. Consequently, NEMA 17 requires 200 steps to complete one full rotation. Since it is a bipolar-type stepper motor, the torque produced by NEMA 17 is greater than the unipolar type with the same motor size [31]. NEMA 17 exhibits high accuracy at low speeds and does not require a lot of power, which is only in the range of 10 V to 12 V [30]. In addition, NEMA 17 was chosen because it is an affordable type of stepper motor.

3) ARDUINO UNO

Arduino UNO is an Arduino board developed using the ATmega328 microcontroller. Previous research used Arduino UNO because it has many input/output pins [32]. Arduino UNO has 14 digital input/output pins (of which six are pulse width modulation outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an in-circuit serial programming (ICSP) header, and a reset button [33]. Arduino UNO also has advantages over other microcontrollers, including its compatibility to run on various operating systems, such as Windows, Macintosh, and Linux. Meanwhile, some microcontrollers are limited to Windows only.

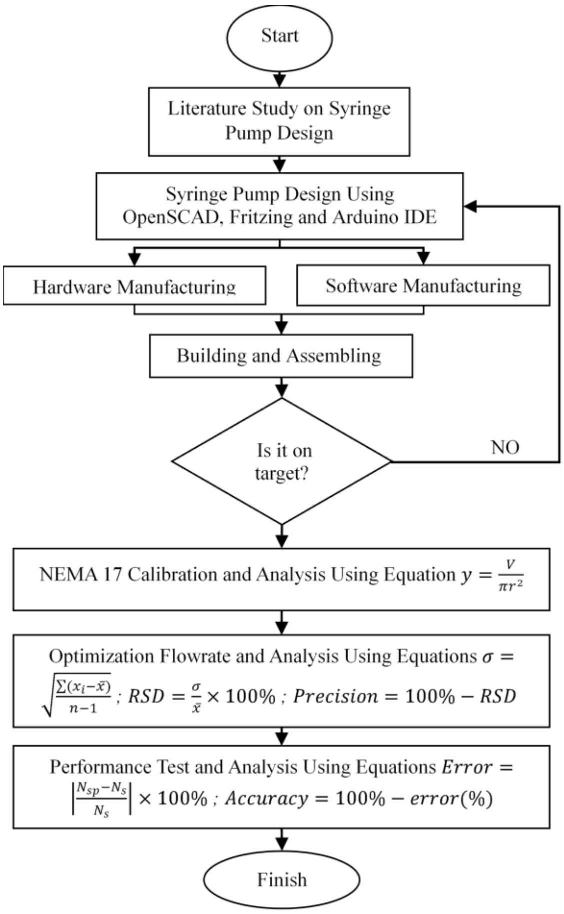

Figure 2. Diagram of research method.

B. RESEARCH DESIGN

This research aimed to design a syringe pump support system that requires low cost but still considered the main features of syringe pumps, such as flow rate with high precision and accuracy. The research design used is shown in Figure 2. A flowchart is used as a foundation to guide the course of the research process from start to finish.

A literature study was collected from several journals to strengthen knowledge and understanding of the research process. As for the syringe pump hardware, the body design was created using OpenSCAD using a 3D printer. Meanwhile, Fritzing was used to create an overview of the control system circuit used in the syringe pump. Meanwhile, the software design for the syringe pump control system was made using the Arduino IDE. After obtaining the hardware and software design, the next stage involved building and assembling the boy parts into a syringe pump. The syringe pump underwent many tests, including calibration, optimization, and performance tests. Data analysis of test results was carried out at each stage of testing. Analysis of each test was carried out until a conclusion was obtained.

The flow rate on the syringe pump was obtained by calculating the number of steps and delay for each step on NEMA 17. Then, the step and delay were inputted into the code on the Arduino UNO as a command to the syringe pump control system. Although it could be run, the syringe pump must be

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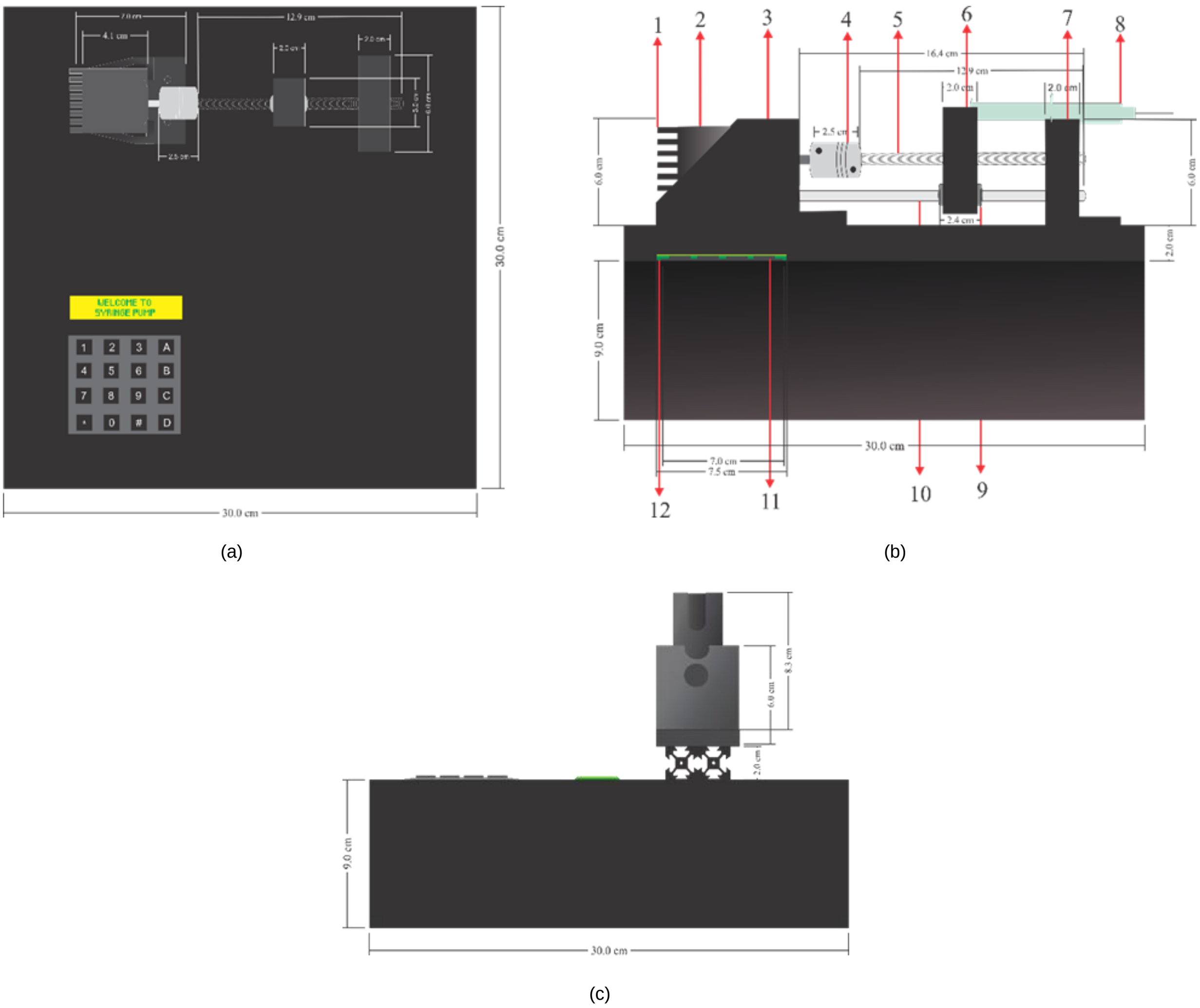

Figure 3. Design of syringe pump (a) top view, (b) side view, and (c) front view.

tested and validated based on the data obtained to work at its best performance.

1) SYRINGE PUMP HARDWARE DESIGN

In this stage, the design of the syringe pump was made. Figure 3 shows the design of the syringe pump made with the description and function. The syringe pump used several components with their respective roles and functions. The heat sink (Figure 3(b) number 1) serves to reduce the heat from the NEMA 17 stepper motor (Figure 3(b) number 2). The stepper motor operates at a very low speed and for a long time, so it has the potential to heat up.

The syringe pump operates based on the conversion of rotational motion from a stepper motor into axial thrust applied to the solution-containing injection (Figure 3(b) number 8). This conversion is facilitated through the utilization of a screw mechanism (Figure 3(b) number 5) linked to the stepper motor via a flexible coupling (Figure 3(b) number 4), thereby constituting an effective force conversion system. In the plunger system, a linear shaft (Figure 3(b) number 10) is also used, which functions as a metal to support the plunger mount so that the screw is not bent and does not increase the load on the stepper motor rotation. A linear bearing is used on the plunger mount to reduce friction with the linear shaft when the plunger mount moves (Figure 3(b) number 9).

The syringe pump body functions as an injection plunger system. The syringe pump body consists of three parts: mount for the stepper motor (Figure 3(b) number 3), mount for plunger (Figure 3(b) number 6) as an injection plunger functions as a plunger system, and mount for barrel (Figure 3(b) number 7) as an injection holder so that the injection does not come off when pushed. This body was designed using 3D software, namely OpenSCAD. OpenSCAD software was used because of the numerous open-source designs created by other researchers, which anyone can utilize. Using open-source designs in OpenSCAD makes it easier for researchers to design syringe pump bodies because OpenSCAD is script-based, which can be easily modified. In addition, the formats exported from OpenSCAD can be read in most Computer-aided design (CAD) tools [34].

The control system for the syringe pump was designed using Fritzing. The Fritzing results were then used as instruction during the control system hardware design. The control system on the syringe pump used several components such as Arduino UNO to run the command program, 4×4 keypad to enter input and LCD 16×2 as a display on the syringe pump (Figure 3 (b) number 11).

2) SYRINGE PUMP SOFTWARE DESIGN

In this stage, software design was done using the Arduino IDE as a code writer application that was uploaded to the Arduino UNO. This stage was initiated by uploading the code to the Arduino UNO via a laptop. This uploading process also aimed to determine the condition of the Arduino UNO in terms

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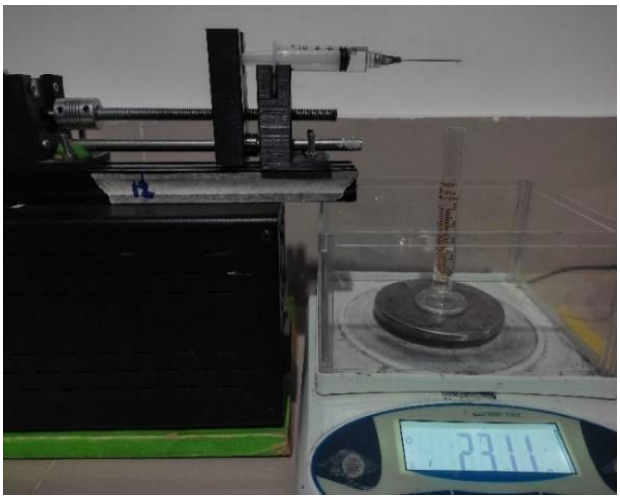

Figure 4. Scheme of the experiment.

of ports, code uploading process, and performance of the Arduino UNO. After the upload process was successful, the LCD turned on, and the writing appeared according to what had been written in the uploaded code. If the LCD does not light up or appear to be written, it indicates issues with the code, wiring on the LCD, or damage to the Arduino UNO port.

After that, input flow rate and volume control was inputted using the keypad. This syringe pump had a flow rate feature that could be adjusted from 1 mL/hour. This syringe pump also had a stop volume feature, which set the syringe pump to stop at a certain volume. In addition, there was also a feature that could change the direction of rotation of the NEMA 17 so that the pump could move forward and backward. The procedure for using this syringe pump was to input the flow rate first and then the stop volume. The flow rate and volume that had been inputted would appear on the LCD. A check would be made on the keypad connection with the UNO Arduino if it did not appear. After the input process was complete, the syringe pump could work. The software was written using C++ and implemented on an Arduino UNO using the Arduino IDE. The code is available in the following repository: https://uns.id/ArduinoProgramCode.

3) DATA VALIDITY

The flow rate of the syringe pump was obtained by calculating the number of steps and delays through the shifts experienced by the syringe pump used in NEMA 17 using (3).

$$y = \frac{V}{\pi r^2} \tag{3}$$

where y is the displacement distance of the syringe pump, V is the volume injected by the syringe pump, and r is the radius of the syringe. After obtaining the number of steps and delay, it was necessary to test and validate the data through precision, error analysis, and accuracy. The experimental process of data validation is shown in Figure 4.

The syringe pump needs to be tested to get the precision value. The level of precision can be determined by calculating the relative standard deviation (RSD) value. The higher the precision level, the smaller the RSD value [35]. The standard deviation (SD) value was determined using (4) in order to calculate the RSD value.

$$\sigma = \sqrt{\frac{\sum (x_i - \underline{x})}{n-1}} \tag{4}$$

where x_i is the research data, $\underline{x}$ is the average of the research data, and n is the amount of data. After determining the SD value [36], (5) and (6) were applied for the precision analysis.

$$RSD = \frac{\sigma}{\underline{x}} \times 100\% \tag{5}$$

$$Precision = 100\% - RSD. \tag{6}$$

The accuracy level of the syringe pump was calculated using error analysis by comparing the data according to (7) with the data obtained through tool testing. The level of accuracy shows how trustworthy a tool is. Equations (7) and (8) were used to calculate accuracy.

$$Error = \left|\frac{N_{sp} - N_s}{N_s}\right| \times 100\% \tag{7}$$

$$Accuracy = 100\% - error(\%) \tag{8}$$

where N_{sp} is the value according to the calculation and N_s is the value obtained through the testing process [37]. In determining the accuracy level of the syringe pump, a performance test was conducted by taking repeated measurements of the volume produced in the range of flow rates of 1 mL/h to 5 mL/h with a time of 30 min.

The material used during the experiment was distilled water due to its ease of determining the density used to determine the volume released by the syringe pump. The choice of liquid types in the experiment does not significantly affect the work of the syringe pump, as its operation is based on the injection displacement when pushed by the syringe pump. Prior research conducted experiments on the effect of viscosity, flow rate, and volume on the syringe pump [38]. The experiment has proved that the viscosity of the solution does not significantly affect the injection process.

IV. RESULTS AND DISCUSSION

A. COST EXPENDITURE RESULT

The low-cost syringe pump was successfully made with a total cost of IDR632,300 or around USD40, as shown in Table I. This syringe pump was developed to be a support system in the electrospinning process. This tool worked by calculating the step and delay on the stepper motor. In addition, this syringe pump had a volume control feature that was useful for adjusting the volume to be released.

The syringe pumps on the market are expensive, such as the NLS20, which costs USD1,829. Features of the NLS20 syringe pump include its capability to fit for one or two syringes, mechanism for a single flow rate, and high accuracy. This tool has the advantage of being used for two syringes so that it can increase the production amount. However, its price is still costly [39]. Another cheaper syringe pump is the NE-300. The NE-300 is priced at USD350 and features multiple syringe sizes and flow rates from 0.73 to 1,500 mL/hr. This syringe pump has a lower price than the NSL20 type, but the NE-300 pump does not have a feature to set the volume so that it will only stop when the stop button is pressed [40]. Compared to other syringe pumps on the market, the syringe pump developed in this research has a volume stop feature. A volume stop feature is useful for adjusting the volume to be released by the syringe pump. This feature can increase the efficiency of researchers since they can do other things.

Some research has also developed low-cost syringe pumps. Previous research developed a low-cost syringe pump with a

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TABLE II
PRE-OPTIMIZATION DATA PRECISION

No	Time (min)	Average Volume (mL)	SD (mL)	RSD
1	5	0.08	0.02	0.22
2	10	0.15	0.02	0.12
3	15	0.24	0.02	0.09
4	20	0.36	0.02	0.06
5	25	0.41	0.02	0.05
6	30	0.51	0.02	0.04
7	35	0.60	0.04	0.07
8	40	0.69	0.04	0.06
9	45	0.78	0.04	0.05
10	50	0.88	0.05	0.06
11	55	0.95	0.05	0.05
12	60	1.05	0.02	0.02
Total RSD				0.07
Precision (%)				93.0

TABLE III
POST-OPTIMIZATION DATA PRECISION

No	Time (min)	Average Volume (mL)	SD (mL)	RSD
1	5	0.08	0.01	0.10
2	10	0.15	0.01	0.04
3	15	0.23	0.02	0.09
4	20	0.32	0.01	0.03
5	25	0.40	0.02	0.04
6	30	0.49	0.01	0.02
7	35	0.56	0.02	0.03
8	40	0.67	0.03	0.05
9	45	0.74	0.05	0.07
10	50	0.84	0.04	0.04
11	55	0.91	0.02	0.02
12	60	1.00	0.01	0.01
Total RSD				0.05
Precision (%)				95.0

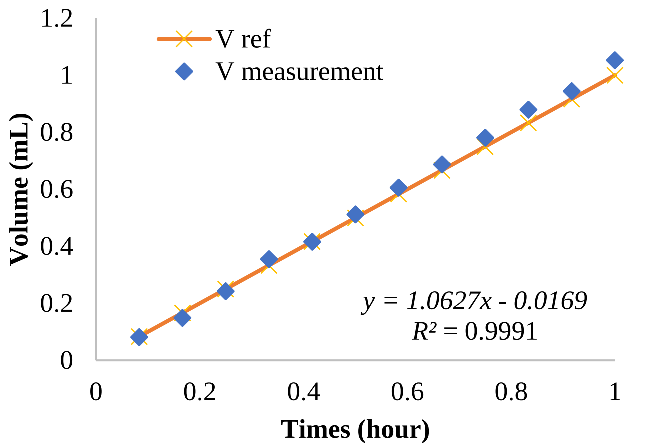

Figure 5. Graph of the relationship between volume and time before optimization.

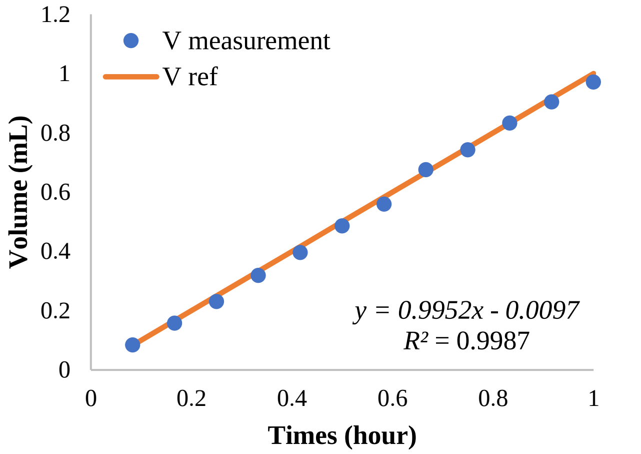

Figure 6. Graph of the relationship between volume and time after optimization.

total cost of USD75 [10]. This tool features low battery consumption and can be used anywhere. Then, another research succeeded in making a low-cost syringe pump with a cost of less than USD75 [11]. Subsequently, research studied the development of low-cost syringe pumps in 2022 [12]. They made a syringe pump costing USD70 or IDR1,145,550. Compared to some prior research, this syringe pump was successfully developed for 45% cheaper while maintaining the same main function of the syringe pump, which was to inject the solution with a precise flow rate and volume.

B. MEASUREMENT OF THE NUMBER OF STEP

This stage was conducted to determine the performance of NEMA 17 and whether it worked according to the code entered. Before starting the measurement, the time needed for the syringe pump to release the volume as expected and the number of steps and delay for each step must be determined. The number of steps for 1 mL/h was 800 steps with a delay of 4,500 ms. After that, the number of steps and delay were entered into the Arduino code and then tested at a flow rate of 1 mL/h.

After conducting five trials by recording the number of steps every 5 minutes in 1 hour, the result showed that the number of steps of the stepper motor was the same as the calculation, which was 800 steps/h. It indicated that NEMA 17 worked according to the code inputted into the program. Thus, NEMA 17 can be used properly in the syringe pump system.

C. OPTIMIZATION OF THE FLOW RATE

The syringe pump measured the average volume of solution from the needle over 60 minutes. The data obtained are shown in Table II and plotted in the graph shown in Figure 5. The regression equation was obtained $y = 1.0627x - 0.016$, where the x-axis is the time, and the y-axis is the volume (Figure 5). When the device was set at a certain Q flow rate at 1 mL/h, for t time, it produced V volume, with Q in mL/h, t in hours, and V in mL. Table II shows if the tool is turned on for 1 hour, the resulting volume is the same as the set flow rate every 5 minutes. It means that the ratio of volume and time is 1. Figure 5 shows the linear regression equation before optimization. The linear regression resulting slope was 1.0627. The outcome did not align with the calculation, exhibiting a difference of around 0.0627.

After that, the measurement volume (blue dots) data were compared with the data reference volume (orange line). The result was that when the flow rate was 1 mL/h, the average volume obtained after 1 hour was 1.04 mL with a precision value of 93,0%. Then, the optimization was carried out based on the stepper travel time for 1 mL of 3,600,000 ms, and then the number of steps and delay was recalculated. After obtaining the number of steps and delays, the trial was repeated. The data obtained after optimization are shown in Table III and plotted in the graph in Figure 6. Based on Figure 6, the regression

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TABLE IV
RESULT PERFORMANCE TEST OF THE FLOW RATE

Data	Volume (mL)				
	1 mL/h	***2 mL/h***	***3 mL/h***	***4 mL/h***	***5 mL/h***
1	0.49	1.00	1.54	2.12	2.39
2	0.51	1.02	1.55	2.11	2.64
3	0.50	1.00	1.55	2.09	2.61
4	0.52	1.03	1.60	2.06	2.53
5	0.51	1.03	1.49	2.14	2.64
Average (mL)	0.51	1.02	1.55	2.10	2.56
Error (%)	2.0	1.6	3.4	5.2	4.3
Accuracy (%)	98.0	98.4	96.6	94.8	95.7

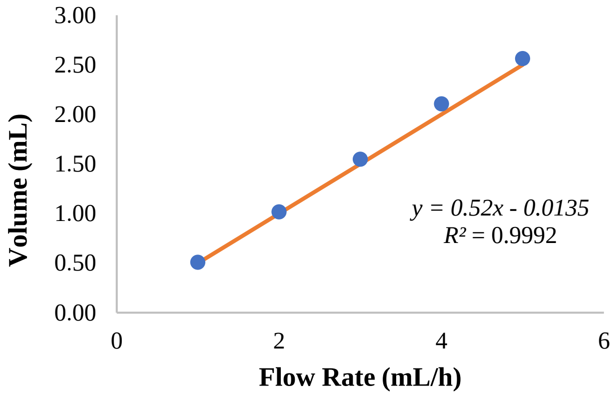

Figure 7. Graph of the relationship between flow rate and volume.

equation was obtained $y = 0.9952x - 0.0097$, where the x-axis is the time, and the y-axis is the volume. Based on (2), after optimization the slope value was closer to 1, meaning that the volume value at a flow rate of 1 mL/h calculated every 5 minutes was almost the same as the calculation. This result indicated that the optimization results at a flow rate of 1 mL/h had a high level of linearity. It was also found that the precision value of the tool after optimization increased from 93.0% to 95.0% with an average RSD value of 0.05. Generally, laboratory equipment's precision level was 95% to 99%, indicating that that the syringe pump was suitable for electrospinning after optimization.

D. PERFORMANCE TEST OF THE SYRINGE PUMP

A performance test of the syringe pump was used to obtain accuracy. Accuracy was used to validate the reliability of the syringe pump. Flow rate and time were used as control variables. In this stage, the flow rate was set at 1–5 mL/h, and the measurement of each flow rate was carried out by measuring the volume injected for 30 minutes. The volume coming out of the syringe was collected with a measuring cup. This measurement was done five times at each flow rate. The results of the syringe pump trial are shown in Table IV.

From the results of the calculations, the average value of flow rate error was 3.3%, so the accuracy was 96.7%. Analysis was also carried out using a graph to obtain the regression equation (Figure 7). From Figure 7, the linear equation was obtained $y = 0.52x - 0.0135$. The x-axis is the flow rate of 1-5 mL/h. From the results of the graph, the value of R^2 was 0.9992, which was close to the value of 1, meaning that the data had high linearity. When the device was set at a certain Q flow rate (1-5 mL/h), for t time, it produced V volume, with Q in mL/h, t in hours, and V in mL. Based on (2), if the tool was turned on for 30 minutes, the resulting volume was half the set flow rate, meaning that the volume and flow rate ratio was 1:2 or 0.5. From the linear regression equation, the resulting slope was 0.52. The result was close to the theoretical calculation.

The use of a low-cost syringe pump is not limited only to the electrospinning apparatus. As previously mentioned, it can be used for medical equipment in hospitals. A syringe pump injects liquid medicine into the patient's body gradually and automatically with the doses given. A low-cost syringe pump with a volume control feature that has been made can support medical treatment activities.

V. CONCLUSION

Based on the research that has been done, an affordable syringe pump was successfully made and could operate well. This syringe pump could produce flow rates starting from 1 mL/h with an error value of less than 5%. The total cost incurred to make this syringe pump was IDR632,300 or 45% cheaper than the previously developed syringe pump. The low-cost syringe pump made in this research had an accuracy rate of 96.7% and a precision rate of 95.0%. This research was expected to solve the problem of the high price of the syringe pumps, especially in their use for electrospinning.

In developing this low-cost syringe pump, obstacles and limitations were encountered: the low speed of the stepper motor overheated the syringe pump when it was used for a long period, which could happen because of the load that the stepper motor was working on. Unfortunately, in this research, installing a heat sink on the stepper motor to reduce the temperature did not yield significant results. Moreover, the data collection process was quite time-consuming. This happened because the data collection was done repeatedly to get precise data.

Future research can utilize gear wheels in the syringe pump system to reduce the load on the stepper motor so that the stepper motor does not heat up during prolonged usage. Furthermore, the findings from this research may provide valuable insights insight for researchers to develop other low-cost tools in other research fields.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHORS' CONTRIBUTIONS

Conceptualization, Dewa Pascal Ariyanto; methodology, Dewa Pascal Ariyanto and Della Astri Widayani; software, Dewa Pascal Ariyanto and Luluk Arifatul Hikamiah; validation, Dewa Pascal Ariyanto and Dewanto Harjunowibowo; formal analysis, Dewa Pascal Ariyanto and Yulianto Agung Rezeki; investigation, Dewa Pascal Ariyanto; resources, Dewa Pascal Ariyanto; data curation, Dewa Pascal Ariyanto; writing—original draft preparation, Dewa Pascal Ariyanto and Yulianto Agung Rezeki; writing—reviewing and editing, Dewa Pascal Ariyanto, Panji Setro Nugroho, Jasmine Cupid Amaratirta, Dewanto Harjunowibowo, and Yulianto Agung Rezeki; visualization, Dewa Pascal Ariyanto; supervision, Dewanto Harjunowibowo and Yulianto Agung Rezeki; project administration, Dewa Pascal Ariyanto and Panji Setyo Nugroho; funding acquisition, Yulianto Agung Rezeki.

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