Design and Implementation of Electronic Control System of Blood Pump for Hemodialysis Machine

Andi Iswahyudi[1], Pratondo Busono[1], Yaya Suryana[1], Anwar Mujadin[1], Dwi Astharini[1]

[1] Electrical Engineering, Department of Science and Technology, University Al Azhar of Indonesia, Komplek Masjid Agung Al Azhar Kebayotan Baru, Jakarta Selatan , Kode Pos 12110

E- mail: andiiswahyudi92@gmail.com, prabusono@yahoo.com, ysuryana@gmail.com

Abstract – **there are three methods of renal therapies, hemodialysis is the primary choise. This is because of the cheaper price compared to the CAPD. In addition, people in indonesia are still not understand the CAPD method. However, there are still many problems in the therapy using hemodialysis machine. This research aims to develop and to know the performance of the electronic control system for blood pump to match the ideal flowrate that will be used in hemodialysis treatment. This research resulting the blood pump charateristic is 179,4 step/ml when using glucose 10% and 168,2 step/ml when using glucose 20%. Based on fluid density, glucose 20% have the best performance with relative of error 0,06% at rpm 5 with 400 ml volume desired. From the result with rpm variation, the system has linearity with the slope M = 8970 step/ml = 4,2 rotation/ml using glucose 10%, and M = 8410 step/ml = 3,97 rotation/ml using glucose 20%. Which mean the slope is equivalent with the increased volume around 48,4 - 53,3 ml. It mean the blood pump rotation is constant and the system is working according the flowrate desired. It is found from the result, that many hardware factors can reducing the blood pump performance such as the roller degradation and the flexibility of the hose.**

Keywords *– Renal Disease, Hemodialysis, CAPD, Blood pump, Flowrate*

BACKGROUND

Hemodialysis,a process where blood is removed from the patient body and pumped into the machine that will filter out toxic substances from the blood, then blood is clean returned again into the body. Principles of Hemodialysis is by applying osmotic process and the artificial kidney ultrafiltration or hemodialysis machines, in removing the remains of the body's metabolism. In hemodialysis process required a hemodialysis machine and a filter as an artificial kidney called a dialyzer, which is used to filter and cleaning the blood from urea, creatinine and metabolic waste substances that are not needed the body.This procedure requires a way into the bloodstream, so that made the connection between an artery and a vein (arteriovenous fistula) through surgery [1]. Controlling blood flowrate is important in hemodialysis therapy. Uncontrolled blood flowrate can dangerous the patients. In the hemodialysis, the blood is taken from the artery and returned process the clean blood to the patient body through vein. The blood is taken from the body using the computer controller peristaltic pump. The purpose of this research is to design an electronic control system for blood pump used in hemodialysis machine. This pump used peristaltic pump with stepper motor with working flowrate is 200 – 400 ml/min. It is refer to most and frequently of working flowrate during hemodialysis is around 200 – 400 ml/min [2]. The blood pump prototype will shown in Figure 1.

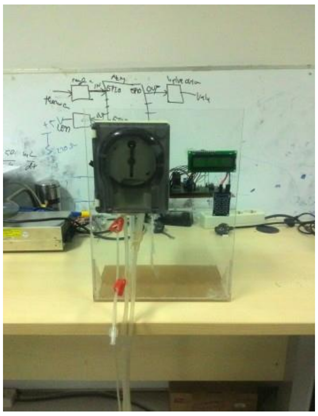


Figure 1. Blood pump protoype.

LITERATURE REVIEW

Blood Pump

Blood pump or peristaltic pump basically works is like the movement that happened in the muscles of the gastrointestinal tract that causes a kind of wave motion causing effects siphoning. In hemodialysis machine peristaltic pump used for pumping variety of fluids. The fluid is contained within a flexible tube fitted inside a circular pump casing (though linear peristaltic pumps have been made). A rotor with a number of rollers attached to the external circumference of the rotor compresses the flexible tube. Usually there will be two or more rollers that occluding the tube, trapping between them a body of fluid. The body of fluid is then transported, at ambient pressure, toward the pump outlet. As the rotor turns, the part of the tube under compression is pinched closed thus forcing the fluid to be pumped to move through the tube. Additionally, as the tube opens to its natural state after the passing of the cam fluid flow is induced to the pump [3].The blood pump for hemodialysis machine shown in Figure 2 [4].

Figure 2. The peristaltic pump [4].

The process of changing the rotation speed from the motor to become flowrate is determined by several parameters, namely length of tube occluded at pump head, the volume of tube, number of rollers, stepper motor rotation in a minute. So it can be expressed in the following equation :

$$\text{Flowrate} = \pi r^2 \times Lt \times n \times \text{rev/min} \qquad (1)$$

Where L contains length of tube and diameter of the roller, it can be expanded to:

$$\text{Flowrate} = \pi r^2 \times \left(\frac{2\pi \times (R+r+t)}{2}\right) \times n \times \text{rev/min} \qquad (2)$$

The final equation of the flowrate is :

$$\text{Flowrate} = \pi^2 r^2 \times (R+r+t) \times n \times \text{rev/min} \qquad (3)$$

Or can be simplified :

$$\text{Flowrate} = Vt \times Lt \times n \times Rpm \qquad (4)$$

Where :

Lt : Length of tube between two rollers (cm)
R : Radius of pump head(cm)
r : Radius of tube(cm)
t : length of tube(cm)
Vt : Volume in tube (ml/cm)
n : number of roller
Rpm : Rotation of pump (revolution per minute)

In case of emergency, all blood pumps have a way to allow hand cranking. Most often, the pump will have a handle, either with the pump head or one that can be inserted into the pump, which can be used to crank the pump. The pump head should be hand cranked just fast enough to keep the venous pressure at the pre-alarm level [3]. The blood pump construction can be seen in Figure 3 [5].

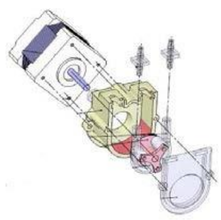


Figure 3. The construction of peristaltic pump [5].

Peristaltic pump in this research consist of three part, namely:

- Stepper motor drive system
- Mechanical system
- Pump head

Stepper Motor Drive System

The stepper motor is dc motor which works by changing the electronic pulses into discrete mechanical movement or in other words the motor is moving based on a given pulse sequence. Therefore, in general needs a stepper motor controller that can generate periodic pulses. The motor's position can be commanded to move and hold at one of these steps without any feedback sensor (an open loop controller), as long as the motor is carefully sized to the application [6].

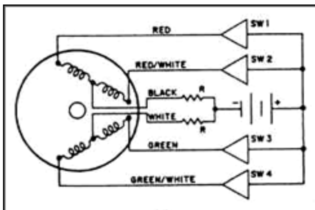
In this research stepper motor used is VEXTA stepper motor hybrid 2 phase bipolar series with 0,9°/step. Because it is easier to control and has higher resolution which is resulting better performance especially better torque. Furthermore, the stepper motor provide precise speed, position, reliability, efficiency, low level of EMI noise, and free from contamination.

In the stepper motor control, there are three methods that are often used, there is wave drive one phase, hi-torque two phase and half step. Hi-torque method has the advantage have an abundant torque compared with half step method, but in this research high torque is needed because behind the pump head there is mechanical system which is trasferring rotation from stepper motor to pump head. So the method used is hi-torque two phase and torque output from stepper motor can be maximized. The wave drive, hi-torque and half step method can be seen in Figure 4 [7].

Sequence	Polarity	Name	Description
0001 0010 0100 1000	---+ --+- -+-- +---	Wave Drive, One-Phase	Consumes the least power. Only one phase is energized at a time. Assures positional accuracy regardless of any winding imbalance in the motor.
0011 0110 1100 1001	--++ -++- ++-- +--+	Hi-Torque, Two-Phase	Hi Torque - This sequence energizes two adjacent phases, which offers an improved torque-speed product and greater holding torque.
0001 0011 0010 0110 0100 1100 1000 1001	---+ --++ --+- -++- -+-- ++-- +--- +--+	Half-Step	Half Step - Effectively doubles the stepping resolution of the motor, but the torque is not uniform for each step. (Since we are effectively switching between Wave Drive and Hi-Torque with each step, torque alternates each step.) This sequence reduces motor resonance which can sometimes cause a motor to stall at a particular resonant frequency. Note that this sequence is 8 steps.

Figure 4. Stepper motor drives method [7].

To control this stepper motor there is a difference from most hybrid stepper motors, the difference found in coil configuration which is generally coil 1 to 4 are color-coded red, blue, green, and black on VEXTA stepper motor's output coil 1 to 4 color code is green, black, red, and blue. In addition to the coil configuration, the step sequence is also different. Sequence of steps for controlling VEXTA stepper motor can be seen in Figure 5 [8].



(a)

FOUR STEP INPUT SEQUENCE (FULL-STEP MODE)*

STEP	SW1	SW2	SW3	SW4
1	ON	OFF	ON	OFF
2	ON	OFF	OFF	ON
3	OFF	ON	OFF	ON
4	OFF	ON	ON	OFF
1	ON	OFF	ON	OFF

(b)

Figure 5. Step sequence for vexta stepping motor drive [8].

Mechanical System

Mechanical system in peristaltic pump uses single belt transmisson with two shafts and two pulleys. This mechanical system used for drive the pump head because at pumping process need compression to get the fluids and torque for pump head at the same time. The pulley which is connected to stepper motor have less teeth than pulley at pump head which is connected to pump head shaft. The mechanical system inside peristaltic pump and the basic theory can be seen in Figure 6 [9] and 7 [10].

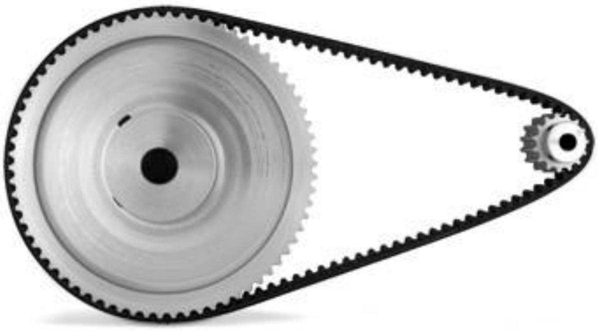


Figure 6. Construction pulley with single belt driven [9].

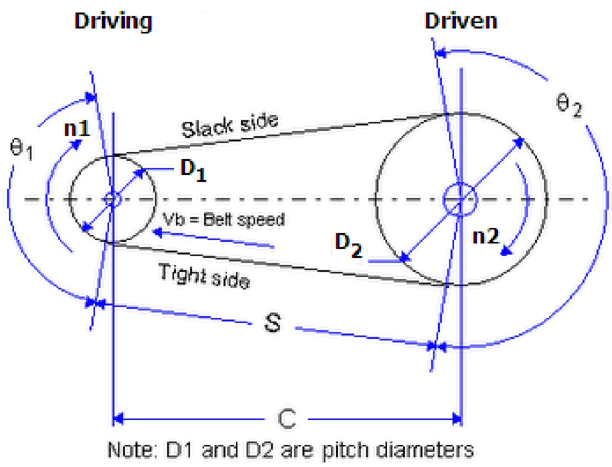


Figure 7. The gear with belt driven theory [10]

Based on that figure we can get the equation of mechanical system is [10] :

$$D_1 n_1 = D_2 n_2 \qquad (5)$$

Where:
D_1 : driver pulley pitch diameter (inch, mm, cm)
n_1 : revolution of driver pulley (Rpm)
D_2 : driven pulley pitch diameter (inch, mm, cm)
n_2 : revolution of driven pulley (Rpm)

Pump Head

Pump head is a part that would pump fluid or liquid by utilizing compressed hose on roller assy so will be causing a pressure. In peristaltic pump, pump head is constructed by many parts. Such as cover, hood, rotor/shaft, roller, and spring loaded rollers. The pump head construction can be seen in Figure 8 [11].

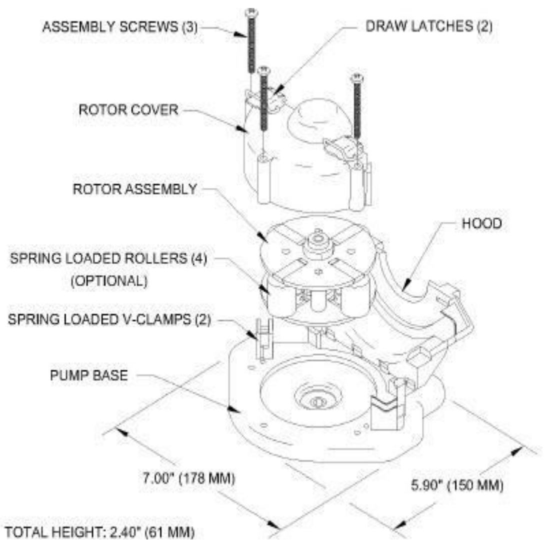


Figure 8. Pump head construction for blood pump [11].

RESEARCH METHODS

The framework of this research begins with literature study and patent review, technical specifications, design hardware and software conceptual, detail design, prototyping, system integration, functional testing, and validation.
Functional testing consist the mechanism of data collection as follows:

a. Finding ρ of each fluid, by observing changes in the parameter of fluid mass.
b. Finding the blood pump characteristic (ml/step), by observing changes in the parameter of volume and number of steps desired.
c. Finding the relative error of blood pump with variation rpm, by observing changes in the parameter of volume generated and desired volume with variation rpm.

RESULT and DISCUSSION

The testing in this research start with testing the density of 1 litre glucose 10% and 20%. it aims to determine the density of the liquid to be tested on a blood pump. The result of density testing is glucose 10% has density 957 kg/m3 and 20% glucose has density 1,011 kg/m3. The result of testing data can be seen in following Table 1 and Table 2.

Table 1. Testing data result of glucose 10%

Larutan gula 10%		
volume(ml)	**massa(gr)**	**rho(g/cm3**
10	71	0,71
20	179,9	0,8995
30	285,2	0,9506667
40	394,3	0,98575
50	501,2	1,0024
60	603,3	1,0055
70	701,7	1,0024286
80	810	1,0125
90	903,1	1,0034444
10	1005,9	1,0059
average		0,957809

Table 2. Testing data result of glucose 20%

Larutan gula 20%		
volume(ml)	**massa(gr**	**rho(g/cm**
10	84,3	0,843
20	184,3	0,9215
30	303,3	1,011
40	409	1,0225
50	519,3	1,0386
60	631,6	1,05266
70	736	1,05142
80	851	1,06375
90	945	1,05
10	1056,8	1,0568
average		1,01112

After knowing the density of each fluid, continued with test of characteristics of the blood pump. The result of testing blood pump characteristic based on fluid density can be seen in Figure 9 and Figure 10.

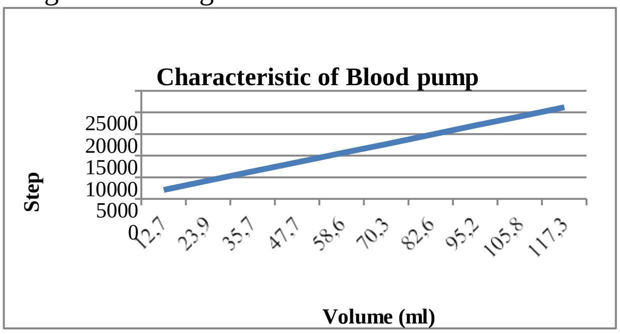


Figure 9. Characteristic of blood pump using glucose 10%

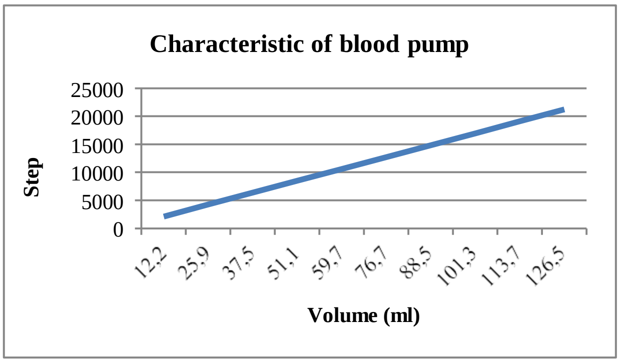


Figure 10. Characteristic of blood pump using glucose 20%.

Based on result, the characteristic of blood pump with different density is 179,4 step/ml using glucose 10% and 168,2 step/ml using glucose 20%. Then the relative of error testing will perform based on fluid density and rpm variation. With gear ratio from mechanical system is 5,3:1 it is equal 2120 steps of stepper motor. The result of testing data can be seen in Figure 11 to Figure 14.

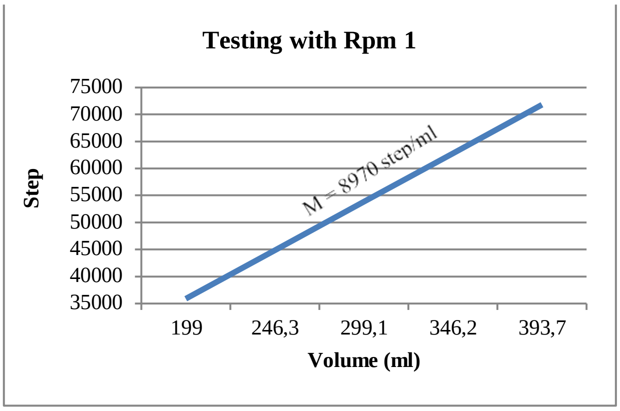


Figure 11. Testing data result of glucose 10% with Rpm 1.

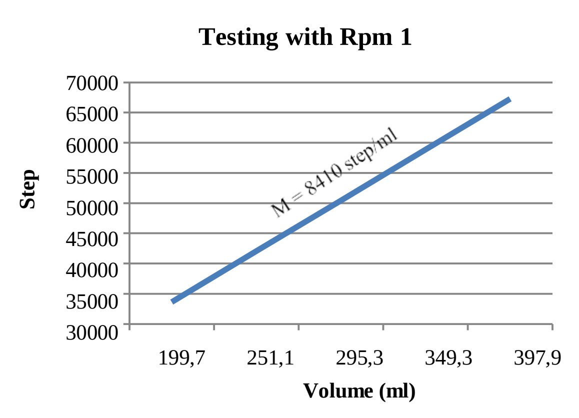


Figure 12. Testing data result of glucose 20% with Rpm 1.

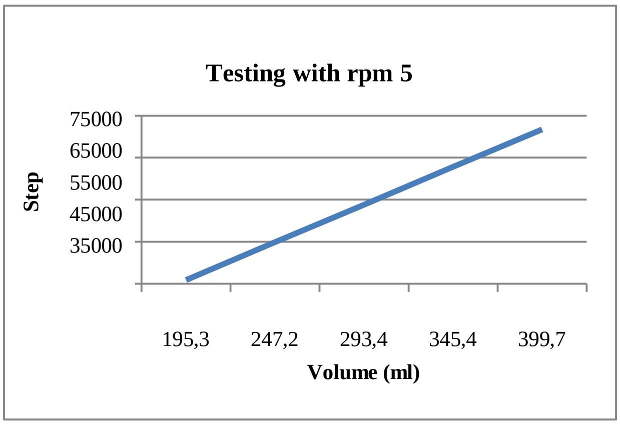


Figure 13. Testing data result of glucose 10% with Rpm 5.

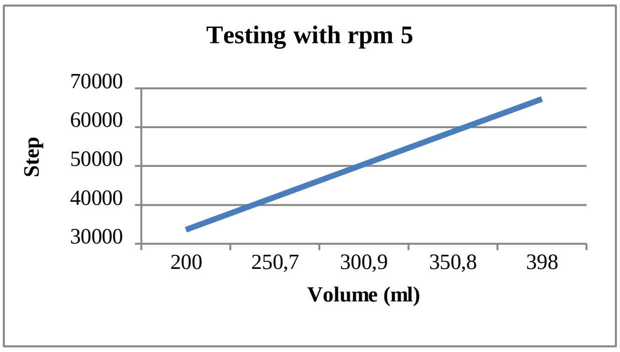


Figure 14. Testing data result of glucose 20% with Rpm 5.

The result relative of error testing rpm 1 with glucose 10% is -0,992%. It means there is still an error because the torque of stepper motor still not enough to pump glucose 10% to produce desired volume with desired steps based on characteristic of blood pump. Increased speed or rpm the relative of error will greater than rpm 1. Because the density of glucose 10% less than density of water.

The result relative of error testing rpm 5 with glucose 20% is 0,06%. It means there is still a little an error because the torque of stepper motor at rpm 5 more than enough and better to pump glucose 20% which is had higher density than glucose 10%.

CONCLUSION

Based on testing and analysis as written in the previous chapter, it can be concluded as follows:

a. The electronic control system for blood pump has been evaluated successfully and systematically. The STM32F3DISCOVERY as controller worked successfully to control the stepper motor speed as a driver of pump head resulting the blood pump charateristic 179,4 step/ml using glucose 10% and 168,2 step/ml using glucose 20%.

b. Based on fluid density of glucose 20% has better performance with relative of error 0,06% at rpm 5 (T_5 = 4,7 ms/step) and 400 ml volume desired, because the higher density and higher rpm pump will be more accurate.

c. From the result with rpm variation, the system has linearity with the slope M = 8970 step/ml = 4,2 rotation/ml using glucose 10%, and M = 8410 step/ml = 3,97 rotation/ml using glucose 20%. Which mean the slope is equivalent with the increased volume around 48,4 - 53,3 ml. It mean the blood pump rotation is constant and the system is working according the flowrate desired.

d. From the result, many factors can causing the pump performance reduced such as the use of roller, bearing and the flexibility of the hose which is can caused crack.

REFERENCES

[1] Hemodialisa,NERS *https://b11nk.wordpress.com/hemodialisa/* (Accessed June 2015.)

[2] Peristaltic Pump, Wikipedia *https://en.wikipedia.org/wiki/Peristaltic_pump* (Accessed June 2015.)

[3] Extracorporeal Circuit, Hemodialysis Devices. *http://dialysis-patient-care.blogspot.com/2010/10/hemodialysis-devices-extracorporeal.html.* (Accessed June 2015)

[4] *http://machinedesign.com/archive/getting-know-stepper-motors.* (Accessed June 2015)

[5] *https://www.damencnc.com/en/components/motors-and-drivers/motor-add-ons/245*. (Accessed June 2015)

[6] Motor Stepper *http://ftrbogi.blogspot.com/2011/01/motor-stepper.html.* (Accessed June 2015)

[7] *http://i.stack.imgur.com/O3elU.png* (Accessed June 2015)

[8] *http://www.ni.com/cms/images/devzone/ph/54327a871307.gif*. (Accessed June 2015)

[9]. *http://www.designatronics.com/products and-solutions/timing-pulleys-and-timing-belts.php.* (Accessed June 2015)

[10] *http://www.smex.net.au/reference/Vbelts02php.* (Accessed June 2015)

[11] *http://www.rolatecpump.com/company.htm* . (Accessed June 2015)