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Design and manufacturing of control circuits for centrifuge device motors

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Abstract

A centrifuge is a tool that functions to separate organelles based on their density. The working principle of a centrifuge uses the principle of rotation or rotation of the tube containing the solution so that it can be separated based on its density. To mix the blood and reagents in the test tube which is placed in the disk hole, rotation is carried out on the disk hole of the test tube using a DC motor. The rotation of the DC motor greatly influences the process of mixing blood and reagents to achieve even mixing results in the blood ready for testing. Regulating motor speed is very important in centrifuge devices. This research designs and makes a control device to regulate the desired speed of a DC motor to move the disk hole of a test tube containing blood to produce evenly mixed blood and reagents. This DC motor control circuit uses a microcontroller circuit that produces control signals to regulate speed to produce optimal DC motor speed. From the results of DC motor load testing with a disk hole filled with 12 test tubes using the PID algorithm by changing the Kp, Ki and Kd parameters for DC motor speed at speeds of 1000 rpm, 2000 rpm, 3000 rpm and 4000 rpm. The best PID parameter setting values with Kp=2 Ki=0.1 and Kd=2 produce steady state times of 15 seconds, 18 seconds, 15 seconds and 18 seconds. Steady State Error 6%, 6%, 4% and 4.5%. The effect of adding the Kd parameter is not significant on changes in steady state time and Steady State Error.

Keyword

Centrifuge device motors, Control circuit, DC motor

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Introduction

Blood testing on patients who have health complaints or want to know their health condition is often carried out using a blood test. Before blood testing is carried out, blood is taken from the patient's body, then mixed with reagents and then placed in a blood tube. When blood is to be tested, it is necessary to ensure that the blood and reagents are evenly mixed. To ensure that the blood is evenly mixed, it is spun using a centrifuge. The blood to be tested is placed in a test tube, then the test tube is placed in the disk hole of the centrifuge tool. Medical personnel use a centrifuge by selecting the blood screening time and required reagents on the Settings panel so that the blood fluid is mixed evenly and ready for testing. Organelles can be divided into groups according to their densities using a centrifuge. In order to separate solutions according to their densities, centrifuges work on the principle of rotation, either of the solution or of the tube that contains it [1][2].

The process of rotating the blood tube in the disc hole of the centrifuge is carried out using a DC motor with a certain rotation speed. This research creates a DC motor control circuit to regulate the speed of the motor used in a centrifuge. The DC motor control circuit design is made using a microcontroller as a DC motor control device to produce optimum motor speed to control the motor used in the centrifuge. To produce optimum rotation of the centrifuge drive motor in this research, Proportional (P), Integral (I), Derivative (D) control is used simultaneously or in other words, PID control is used. The use of the PID algorithm is widely used in control system applications in industry. Many control methods are used to control speed than DC motors. Proportional - Integral - Derivative (PID) controllers are often used in several types of DC motors in various industrial applications [3] [4][5]. The success of using a PID controller is determined by the accuracy of determining the constants P, I and D specified on the controller [6]. While there are benefits to each control action, the proportional control action stands out for its ability to enhance the transient response, particularly the rise and settling times. The difference between the desired quantity and its actual value, or the amount of the error signal, determines the proportional controller's output. The purpose of an integral controller is to generate a system response with zero steady state error. The characteristics of a derivative operation are also shared by a differential controller. A very substantial and quick change will occur from a sudden change in the controller input. An impulse-shaped signal is produced by the output when the input signal changes abruptly and rises (as in the case of a step function). In contrast, the controller output remains constant when the input signal does not change [7]. In order to prevent the corrected error from entering the previous amplification stage of the plant, the PID controller attempts to correct the error it receives from the difference in signal input and tachometer output signal. PID controllers have the capacity to recall past events and permit non-zero output in the event of a null entry. Therefore, a status error stationary equal to zero is permitted by this controller. In exchange, the integrator adds a pole to the closed loop function, which causes the system's stability to decrease [8].

In order to support human activities such as industrial applications, moving objects like conveyor belts, pumping water from underground to the surface, cooling rooms with fans, robotics, and electric vehicles, DC motors are now widely used and considered essential [9]. In many different industrial applications where a broad speed range is required, DC motors are commonly used. One benefit of DC motors could be their capacity to manage the speed. The deliberate alteration of speed, which can be accomplished manually or automatically, is referred to as speed control. Different controllers are used to regulate the speed of DC motors; the most widely used controllers are the traditional PI and PID controllers [10]. In industries, over 95% of the controllers used are PID controllers, this is due to its high efficiency and ease of implementation. The PID controller is widely used in industries to solve various control problems [11].

Methods

The stages of making this tool are carried out by designing the centrifuge tool system block, preparing the components of the tool to be made, the program that will be used on the microcontroller as a control device, making the circuit on the PCB and wiring the DC motor [7]. Next, a trial was carried out on the DC Motor rotation speed control process with the control circuit that had been created.

PID control equation in the form of Laplace transforms can be written:

$$\frac{U(s)}{E(s)} = K_c[1 + \frac{1}{T_i S} + T_d S \quad (1)$$

With the completion of a frequently used method that is backward difference method can be explained as follows:

z0 = sampling number to n (now underway)

z-1 = sampling time to n-1

z-2 = sampling time to n-2, and so on

With Backward difference methods PID equation becomes:

$$\frac{U(s)}{E(s)} = K_c[1 + \frac{1}{T_i S} + T_d S] \text{ backward Defference} \rightarrow \text{U(t)=} U_{(t)} = e_{(t)} K_c[1 + \frac{T_s}{T_i(1-z^{-1})} + T_d \frac{(1-z^{-1})}{T_s}] \quad (2)$$

The sampling time interval can be expressed:

$$\text{U(t-1)} = K_c e[t-1) + \frac{K_C.T_s}{Ti} \sum_{i=0}^{t=1} e(t) + \frac{T_d(e(t-1)-e(t-2))}{T_s} + u_0 \quad (3)$$

By subtracting the initial equation thus becomes:

$$U_{(t)} = u(t-1) + K_c[e(t) - e(t-1)] + \frac{K_C T_s}{Ti} e(t) + \frac{K_C T_d}{Ts} [e(t) - 2e(t-1) + e(t-2)] \quad (4)$$

From the concept of the digital PID control equation (4), is expected to be translated into microcontroller programming Flowchart are shown in Figure 1. PID programming on the microcontroller uses C language with the following explanation:

The error value is obtained from the difference in the Set Point Value minus the value of the sensor reading (PV). To find the size of the Proportional parameter, it is obtained from multiplying the Proportional constant (KP) with the Error. Integral Parameters are obtained from the accumulated amount of error changes multiplied by the Integral Constant (KI). The Differential Parameter is the difference from the current error minus the previous error multiplied by the Differential Constant (KD). The three parameters are executed within the sampling time range. PID output is the sum of the three Proportional parameters, Integral Parameters and Differential Parameters.

The microcontroller control system block using the PID algorithm is shown in Figure 2 and the components of the Centrifuge device are shown in Figure 3. The steps to apply the PID algorithm to control the motor driving the centrifuge device begin by translating the PID mathematical equation into a programming language that will be run on the microcontroller as a device to control the speed of the centrifuge motor.

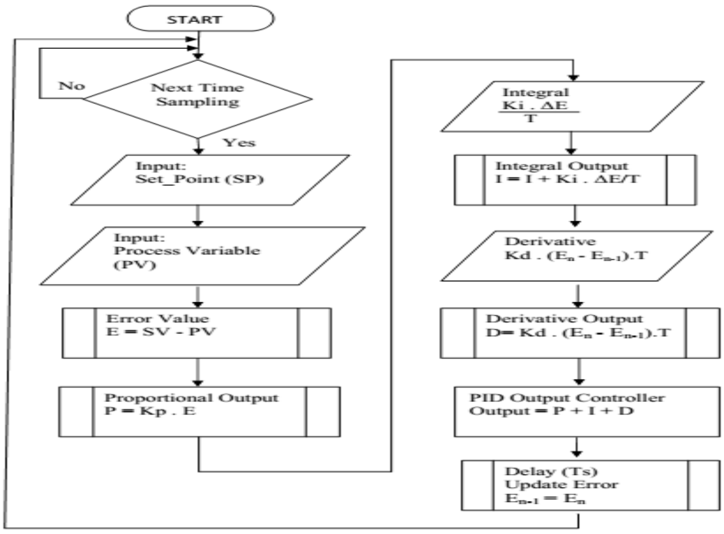


Figure 1. Flowchart of Microcontroller Programming

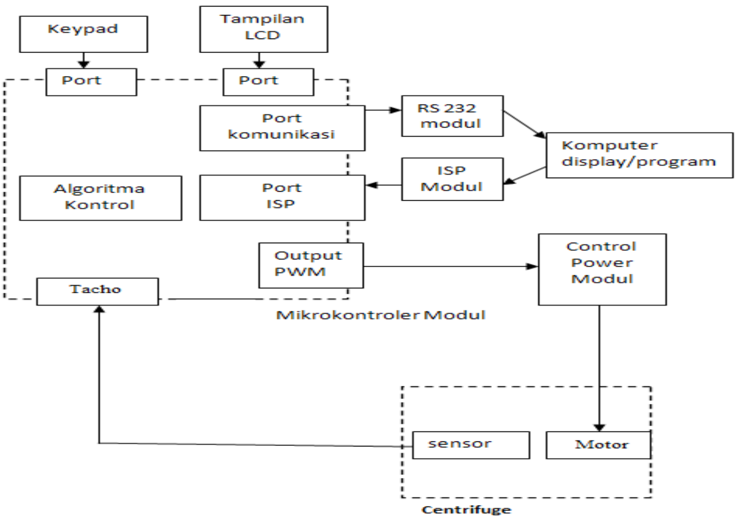


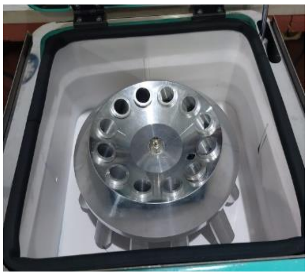
Figure 2. Block diagram of the centrifuge device control system with PID control

DC motor as a centrifuge device driver

The DC motor used in the centrifuge device in making this tool has specifications as shown in Table 1. Direct current DC motors are frequently utilized in industrial applications because of their superior performance, dependability, and ease of control. For DC motor speed control, robustness is the most important design criterion, followed by system performance [4][12][13].

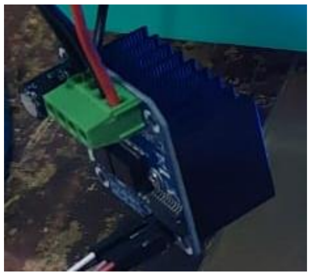
Table 1. Specification DC motor on centrifuge device.

Items		Specifications
Voltage	:	12 -36 Volts DC
Current	:	15 – 20 A
Speed	:	6000 – 18000 rpm



Disk Hole Blood Tube

Motor DC



Circuit Driver Motor

Operator Panel

Microcontroller ATmega as Controller

Figure 3. Centrifuge device components

DC Motor control circuit

With the development of technology, various microcontrollers are available with various choices on the market. With increasingly cheaper prices and better features to be applied for various purposes, especially for control applications [14] [15]. The DC motor control circuit created consists of a microcontroller circuit that issues a PWM signal to drive the voltage applied to the motor with a pulse width controlled by the microcontroller to produce the desired motor speed.

Result and discussion

User panel function testing, motor speed testing, and changing the amount of motor load (number of tubes in the disk hole) were carried out to determine the performance of the centrifuge device being made. From the results of observations in Table 2 of the experiment by changing the PID parameter values, the steady state error (tss) and steady state error (ess) values are produced at the values Kp=2, Ki=0.1 and Kd= 2 while the responses can be depicted in Figures 4 to Figure 7.

In FIGURE 4 Motor speed graph at 1000 RPM, initially the motor rotates and overshoot occurs at maximum surge in the 4th second of 1400 RPM exceeding the set point value then decreases until the steady state error condition at the 15th second is 6 percent. In Figure 5 Motor speed graph at 2000 RPM, at first the motor rotates and slight spike at

8 seconds of 2200 RPM exceeding the set point value then decreases until the steady state error condition at the 18th second is 6 percent.

Table 2. Results of several PID parameter settings on the response of the DC centrifuge motor

Set Point (rpm)	1000	2000	3000	4000
Parameter Kp=3 Ki=0.1 Kd=0				
Steady State(tss)(Second)	23	15	32	35
ERROR (ess) (%)	6	3	6	7.5
Parameter Kp=2 Ki=0.1 Kd=2				
Steady State(tss)(Second)	15	18	15	18
ERROR (ess) (%)	6	6	4	4.5
Parameter Kp=2 Ki=0.1 Kd=10				
Steady State(tss)(Second)	26	16	26	29
ERROR (ess) (%)	6	3	6	6
Parameter Kp=2 Ki=0.07 Kd=0				
Steady State(tss)(Second)	19	30	40	47
ERROR (ess) (%)	6	6	4	6
Parameter Kp=2 Ki=0.1 Kd=0				
Steady State(tss)(Second)	23	17	26	32
ERROR (ess) (%)	6	6	4	6

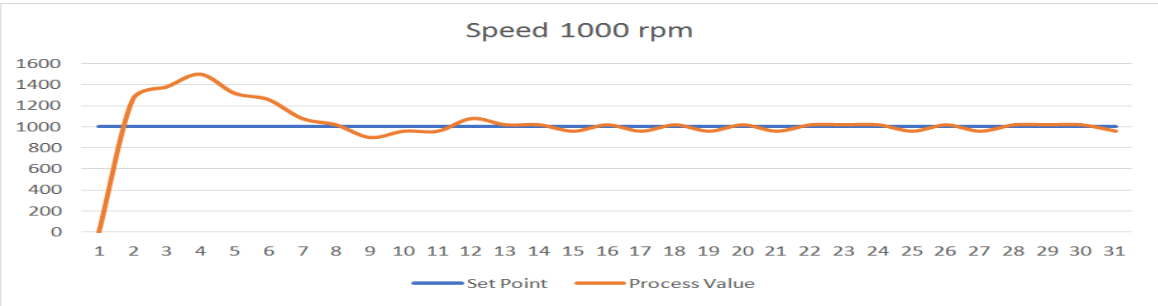


Figure 4. Motor speed graph at 1000 RPM

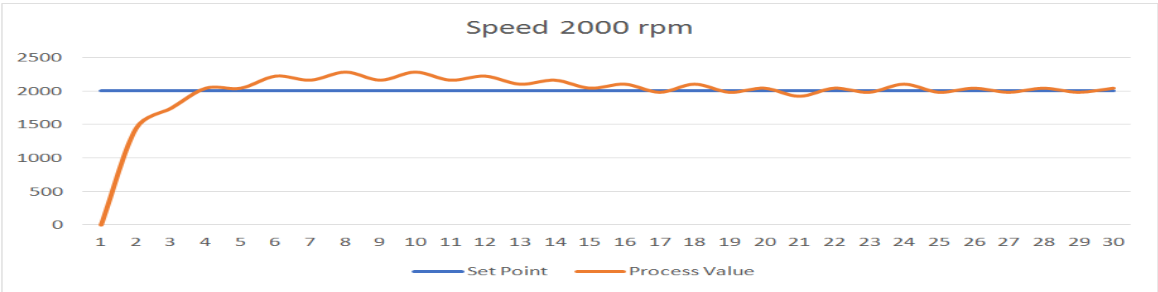


Figure 5. Motor speed graph at 2000 RPM

In Figure 6. Motor speed graph at 3000 RPM, Initially the motor rotates towards the set point at the 12th second and no over shoot occurs until the steady state error condition at the 15th second is 4 percent. In Figure 7 Motor speed graph at 3000 RPM, Initially the motor rotates towards the set point at the 15th second and no over shoot occurs until the steady state error condition at the 18th second is 4.5 percent.

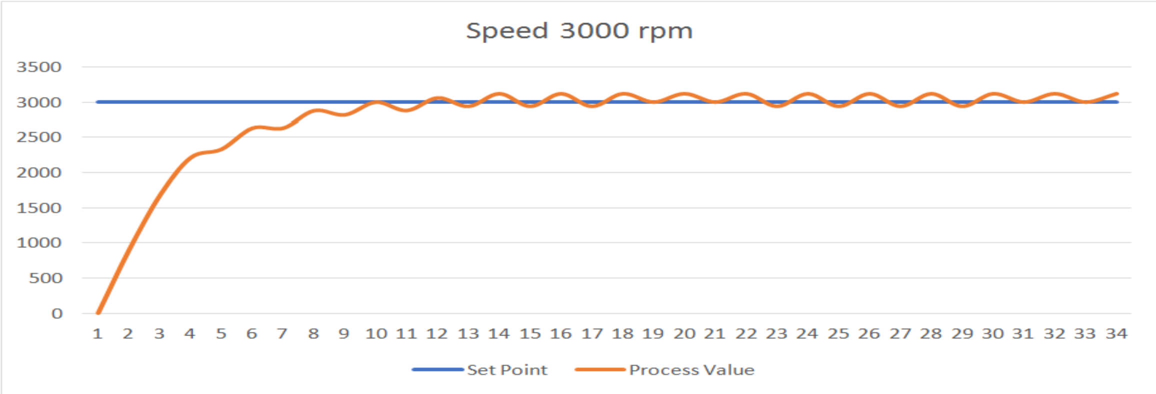


Figure 6. Motor speed graph at 3000 RPM

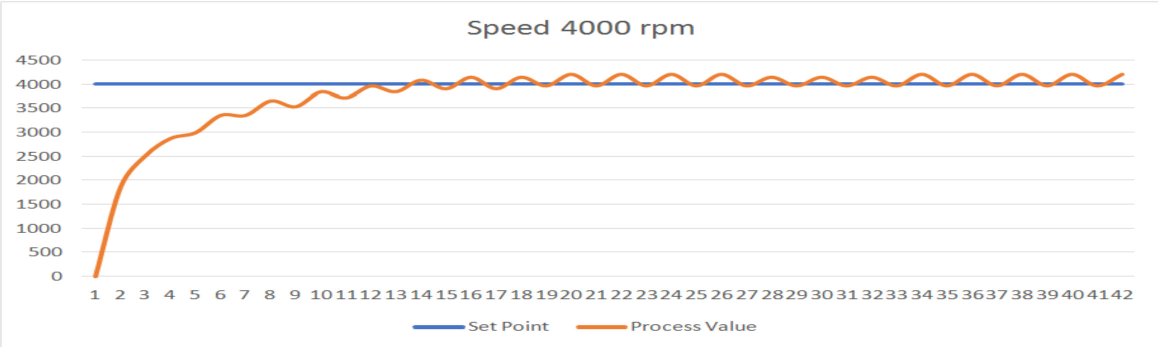


Figure 7. Motor speed graph at 4000 RPM

Conclusion

From the results of DC motor load testing with a disk hole filled with 12 test tubes using the PID algorithm by changing the Kp, Ki and Kd parameters for DC motor speed at speeds of 1000 rpm, 2000 rpm, 3000 rpm and 4000 rpm. The best PID parameter setting values with Kp=2 Ki=0.1 and Kd=2 produce steady state times of 15 seconds, 18 seconds, 15 seconds and 18 seconds. Steady State Error 6%, 6%, 4% and 4.5%. The effect of adding the Kd parameter is not significant on changes in steady state time and Steady State Error.

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References

[1] P. Setyadi, A. Premono, W. Sugita, and I. Suryana, "Seminar Nasional-XX Proses Manufaktur Alat Pemisah Plasma Darah Dengan Metode Sentrifugasi," 2021.

[2] R. Alfian et al., "Perancangan Mesin Centrifuge Berbasis Kontrol Pulse Width Modulation (pwm) dengan menggunakan Mikrokontroller Node MCU Untuk Memisahkan Partikel Organel Darah."

[3] R. S. Widagdo, B. Hariadi, and K. Setyadjit, "Modelling and Analysis of Ziegler-Nichols and Chien-Hrones-Reswick Tuning PID on DC Motor Speed Control," Jurnal Teknologi Elektro, vol. 14, no. 1, p. 23, Feb. 2023, doi: 10.22441/jte.2023.v14i1.005.

[4] E. K. Ibrahim, A. H. Issa, and S. A. Gitaffa, "Optimization and Performance Analysis of Fractional Order PID Controller for DC Motor Speed Control," Journal Europeen des Systemes Automatises, vol. 55, no. 6, pp. 741–748, Dec. 2022, doi: 10.18280/jesa.550605.
[5] "View of DC Motor Speed Control with Proportional Integral Derivative (PID) Control on the Prototype of a Mini-Submarine".
[6] M. M. El-Saadawi, E. A. Gouda, M. A. Elhosseini, and M. S. Essa, "Identification and Speed Control of DC Motor Using Fractional Order PID: Microcontroller," European Journal of Electrical Engineering and Computer Science, vol. 4, no. 1, Jan. 2020, doi: 10.24018/ejece.2020.4.1.170.
[7] R. Kristiyono and Wiyono, "Autotuning fuzzy PID controller for speed control of BLDC motor," Journal of Robotics and Control (JRC), vol. 2, no. 5, pp. 400–407, Sep. 2021, doi: 10.18196/jrc.25114.
[8] S. J. Hammoodi, K. S. Flayyih, and A. R. Hamad, "Design and implementation speed control system of DC motor based on PID control and matlab simulink," International Journal of Power Electronics and Drive Systems, vol. 11, no. 1, pp. 127–134, Mar. 2020, doi: 10.11591/ijpeds.v11.i1.pp127-134.
[9] E. S. Rahayu, A. Ma'arif, and A. Cakan, "Particle Swarm Optimization (PSO) Tuning of PID Control on DC Motor," International Journal of Robotics and Control Systems, vol. 2, no. 2, pp. 435–447, 2022, doi: 10.31763/ijrcs.v2i2.476.
[10] A. Idir, K. Khettab, and Y. Bensafia, "Design of an Optimally Tuned Fractionalized PID Controller for DC Motor Speed Control Via a Henry Gas Solubility Optimization Algorithm," International Journal of Intelligent Engineering and Systems, vol. 15, no. 3, pp. 59–70, Jun. 2022, doi: 10.22266/ijies2022.0630.06.
[11] A. M. Abba, T. Karataev, S. Thomas, A. M. Ali, I. Yau, and S. A. Mikail, "Optimal PID Controller Tuning for DC Motor Speed Control Using Smell Agent Optimization Algorithm," FUOYE Journal of Engineering and Technology, vol. 7, no. 1, Mar. 2022, doi: 10.46792/fuoyejet.v7i1.740.
[12] A. Ma'Arif, Iswanto, N. M. Raharja, P. A. Rosyady, A. R. C. Baswara, and A. A. Nuryono, "Control of DC Motor Using Proportional Integral Derivative (PID): Arduino Hardware Implementation," in Proceeding - 2020 2nd International Conference on Industrial Electrical and Electronics, ICIEE 2020, Institute of Electrical and Electronics Engineers Inc., Oct. 2020, pp. 74–78. doi: 10.1109/ICIEE49813.2020.9277258.
[13] "1493-1497".
[14] "DC Motor Rotary Speed Control with Arduino UNO Based PID Control _ Rikwan _ Control Systems and Optimization Letters".
[15] A. Ma'arif and A. Çakan, "Simulation and arduino hardware implementation of dc motor control using sliding mode controller," Journal of Robotics and Control (JRC), vol. 2, no. 6, pp. 582–587, Nov. 2021, doi: 10.18196/jrc.26140.