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DC Motor Controller Using Full State Feedback

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***Abstract*— This paper discusses the implementation of a full state feedback control system on DC motors to stabilize the speed of DC motors and fight the disturbances given to DC motors. Modern controls such as full state feedback use 2 sensor inputs, namely the Hall effect speed sensor OH42E and the INA219 current sensor and use 3 parameters namely $K1$ (Constant 1), $K2$ (Constant 2), and KI (Integral Constant) in designing the controller, the goal is to get a good system response according to the desired design specifications. The test was carried out with a hardware-in-the-Loop (HIL) scheme which uses an Arduino microcontroller as a DC motor plant control device in the form of a control mathematical model entered in the Arduino IDE software and by trial and error to find the desired response value. The test results showed that at the values of $K1 = 1, K2 = 1, KI = 0.9$, a stable system response was obtained with $tr\,(s) = 3$, $ts\,(s) = 4$, and $Os\,(\%) = 7\%$. The addition of an integral constant (KI) value affects a short rising time but is inversely proportional to a high overshoot value as well. Varying the values of $K1$ and $K2$ as multipliers on the sensor values has an impact on the stability of the system response or oscillations. The stability of this system response indicates that full state feedback can be relied upon as a control system.**

Keywords*— state feedback; control system; motor DC.

I. Introduction

The controlling system is generally divided into classical and modern control [1][2][3]. In the classic control system there is only 1 sensor input while the modern control has 2 or more sensor inputs so that it has high complexity. Modern controls such as full state feedback use 2 sensor inputs, namely the Hall effect speed sensor OH42E and the INA219 current sensor and use 3 parameters namely $K1$ (Constant 1), $K2$ (Constant 2), and KI (Integral Constant) in designing the controller, the goal is to get a good system response according to the desired design specifications. The DC motor controller system using full state feedback is a simple prototype used to represent problems related to DC motor speed control [4]. For example, the speed problem of a DC motor in a lift with a different load where the control system stabilizes the response and counteracts the interference given to the DC motor.

In a previous study by Fahmizal (2019) with the title "Design of a State Feedback System using Block Pole Placement. In this study, it was discussed to get the gain parameter K in the LQR control. Furthermore, by changing the weighting matrix Q will be obtained a variation in gain K. In this study, five types of variations in the Q weighting matrix were obtained. While the matrix of the element R is led by the value of one. In an earlier study by Irsyadi (2019) with the title "Application of Full State Feedback Control in HIL (Hardware In-The-Loop) Ball and Beam Systems". In this study, it was discussed that Full state feedback control produced a similar response in stabilizing the ball and beam system in all test schemes carried out with the largest error steady state value of 0.19 cm in the real plant simulation scheme. Based on previous research, the full state feedback control system was chosen on the grounds of ease of design of control based on the desired performance and has high complexity.

II. Literature Review

A. Designing Full State FeedBack

Full state feedback is a control system method used. The way the full state feedback method works is based on the state space design method. The purpose of the full state feedback method is that it is possible to assign a set of poles to the closed loop system that will correspond to the desired dynamic response. Basically. Mainly, full state feedback will consider all variables to be feedback. If one of the variables is not available then use the estimator state. The state estimator serves to estimate the value of the unavailable variable based on the sensor measurement value from the control system output.

Designing a full state feedback method control the things to know are to know the inputs, outputs, and states through the calculation of state space by forming its mathematical modeling and then it will be expressed in vector form. Other names of the full State feedback control are integral state feedback, servo state feedback, and state feedback integral [6]. Full state feedback equations can be assumed such as Equations (1), (2), (3), (4), and (5).

$$\dot{x} = Ax + Bu \tag{1}$$

$$y = Cx \tag{2}$$

$$u = uI + uf = ekI - Kx \tag{3}$$

$$\dot{e} = r - y = r - Cx \tag{4}$$

$$e = \int \dot{e}\, dt \tag{5}$$

Where, x is the vector state, e is the output of the integrator, $\dot{e}$ is the combined output between the reference and the sensor feedback, u is the control signal, y is the output signal, r is the reference signal, i is the feedback output signal, kI is the integral constant parameter, K is the feedback constant sensor, A is the constant matrix, B is the constant matrix , and C is the constant matrix [7][8][9]. The system block diagram can be seen in Fig. 1.

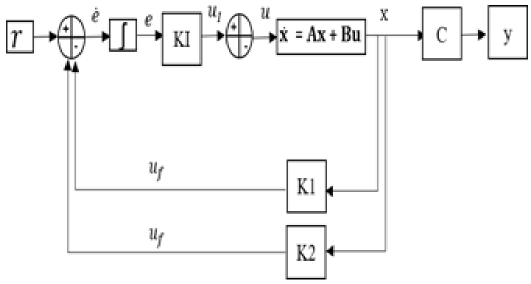

Fig. 1. System Block Diagram

In the formulation of programming languages in the Arduino IDE software, it is necessary to translate from mathematical calculations into variable coding sentences [10]. The application used first calculates the error value from the difference in setpoint speed to the actual speed of the DC motor, then calculates the next error value by summing the current error value. It can be seen in Fig. 2.

```
error = sp - rpm ;
sum_error = sum_error + error;
motorPwm =  (kI*sum_error)-((k1 * rpm) + (k2 * data_arus)) ;
```

Fig. 2. Mathematical Coding

DC (Direct Current) motor is a device that converts electrical energy into rotational mechanical energy by requiring a direct current voltage supply. DC motors are used specifically where the need for high torque or fixed acceleration for a wide speed range. By applying a voltage difference at the two terminals, the motor will rotate in one direction, and if the polarity of the voltage is reversed, the direction of rotation of the motor will be reversed as well [11]. The Hall Effect OH42E Encoder Sensor is used to convert linear or rotary motion into a digital signal, where the rotary sensor monitors the rotary motion of a device. This sensor transmits a certain amount of pulses for each spin that will generate a box wave on the rotated object and will produce the form of an encoding in a certain array. The physical form of the DC motor with Encoder Hall Effect OH42E used is as shown in Fig. 3.

Fig. 3. Motor DC with Encoder Hall Effect OH42E

The dimensional shape of the Hall Effect OH42E Encoder sensor is fairly small with a diameter of 1.5 cm^2, using a voltage of 3.3 volts, and there are two outputs that go to the controller insert. Looks like in Fig. 4.

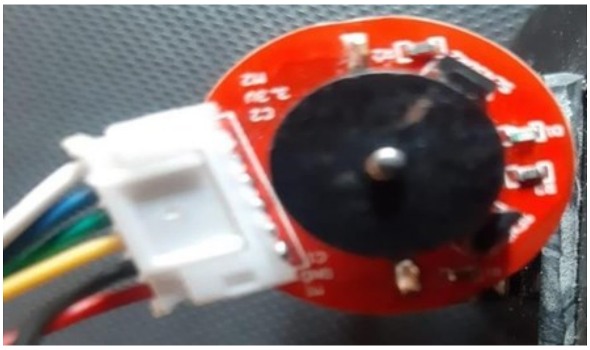

Fig. 4. Sensor Encoder Hall Effect OH42E

B. Photoplethysmography (PPG)

Arduino Uno R3 is a microcontroller development board based on the Atmega328P chip. Arduino Uno R3 is a naming that indicates that the microcontroller board has been developed or has been revised 3 times. Arduino Uno has 14 pins that can be used as inputs and outputs, of which 6 can be used as output pulse width modulation, besides that there are also 6 analog input pins, 16 MHz crystal oscillators, power jack sockets, ISP heads, reset buttons and USB connections [12]. In Arduino Uno R3 programming, you can directly use a USB cable that is connected between Arduino Uno and a PC. Researchers use this microcontroller board because it has complete facilities such as complete input-output pins, and the voltage source for the sensor in making this prototype the specifications of the Arduino Uno R3 can be seen in Table I.

TABLE I. SPESIFICATIONS ARDUINO R3

Specifications	Information
Microcontroller	Atmega328P
Working Voltage	5 volts
Input Voltage	7 – 12 volts
Pin I/O Digital	14
Pin Analog	6
DC current of each I/O pin	20 mA
Current DC current of 3.3 V	50 mA
Flash Memory	32 Kb
BLEMISH	2 Kb
EEPROM	1 Kb
Clock Speed	16 MHz
LED *Built In*	13
Long	68,6 mm
Wide	53,4 mm
Heavy	25 g

C. Current Sensor INA219

The current sensor provides an economical and precise solution for DC voltage. Common applications include motor control, load detection, power supply and DC-to-DC control converters, and overcurrent fault detection. The INA219 sensor is a sensor that functions to measure 2 parameters at once, namely voltage (Volts) and current (Ampere). The voltage that can be measured is up to 26v while for the current it is up to 3.2 A. For communication, this sensor uses I2C, namely SDA and SCL [13][18]. The INA219 current sensor display looks like Fig. 5.

Fig. 5. Current Sensor INA219

Operating voltage is 3.3-5V, Maximum Voltage is 26 (DC), Maximum Current is 32 A, Sensitivity is 0.8 mA, Operating temperature is -40 ~ 150 ° C.

D. Driver Motor DC L298N

It is a number composed of transistors used to drive DC motors. The motor can indeed rotate only with DC power, but it cannot be adjusted without using a driver, so a series of drivers is needed that functions to regulate the work of the motor. The dc source voltage that can be applied is between 5V- 35VDC, while the input voltage is 5VDC, this motor driver uses a full H-bridge circuit with IC L298 with protection when heat and overcurrent occur [12][14]. The physical shape of the L298N is as shown in Fig. 6.

Enable A Serves to activate the output part of motor A, Enable B serves to activate the output part of motor B. Control Pin As a control of the rotation and speed of the motor connected to the Microcontroller.

If it gives high logic (1) or low logic (0) one on IN1/IN2 for motor A and IN3/IN4 for B in determining the direction of rotation of the DC motor (CW/CCW/not rotating) and also sends a PWM wave signal through ENA/ENB to regulate the rotating speed of the DC motor [15][16][19].

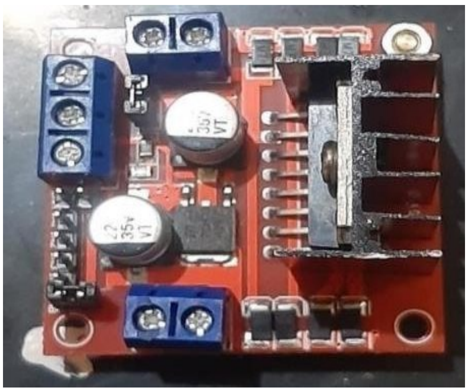

Fig. 6. Physical Form of L298N Motor Driver

III. METHODS

This research uses experimental and design methods. The experiment carried out is to pay attention to the sensor used whether it can run according to its function. Meanwhile, the design of this research has several stages of system design, both in hardware design and software design.

A. System Design

The design of the system hardware for DC motor controllers with state feedback was initially carried out by detecting the speed of the DC motor with the Hall Effect OH42E Encoder sensor and the current flowing in the DC motor, the detection of speed and current later in the form of a digital signal which is an input for the microcontroller that the researcher used in the study [16].

The study used the Atmega328P microcontroller which is packaged in the form of a microcontroller board, namely Arduino Uno R3. Arduino Uno R3 was chosen because this board has a lot of compatibility with various types of sensors and also other modules. The design diagram block of this tool is shown in Fig. 7.

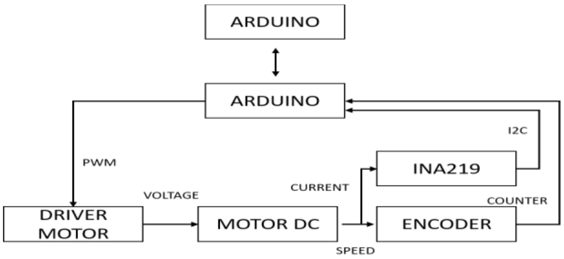

Fig. 7. Block Diagram Designing Tools

The first process, namely Arduino Uno R3, is connected to a voltage source, after that the Hall Effect OH42E Encoder sensor and INA219 current sensor are connected to Arduino Uno R3 where the Hall Effect OH42E Encoder sensor will produce a digital signal while the INA219 current sensor reads the current used by the DC motor and will produce a digital signal with I2C communication [17][20]. Data readings from the Hall Effect OH42E Encoder sensor and INA219 current sensor are sent to the Arduino Uno R3 with a full state feedback control system and then generate a PWM signal to the motor driver. The wiring diagram design of this tool looks like in Fig. 8.

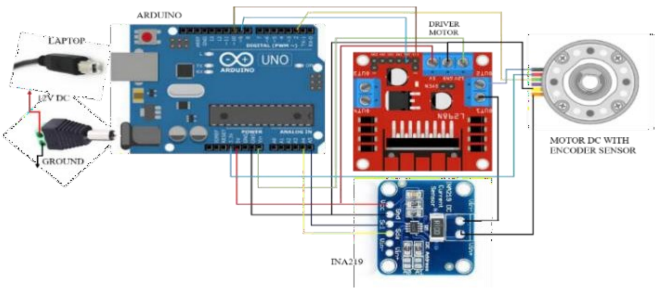

Fig. 8. Wiring Diagram

B. System Software Design

In creating a program that will be downloaded into the Arduino Uno board, researchers use the Arduino IDE software. This application is useful for creating, opening, and editing Arduino source code. The language used in this Arduino IDE programming is Language C. Flowchart of the DC motor controller system with state feedback looks like in Fig. 9.

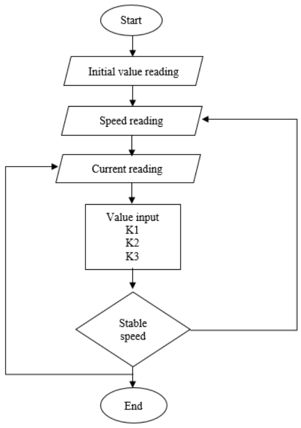

Fig. 9. Tool Flowchart

IV. Discussion

In this section is a hardware implementation using Arduino, l298N motor driver, INA219 and DC motor. Looks like Fig. 10.

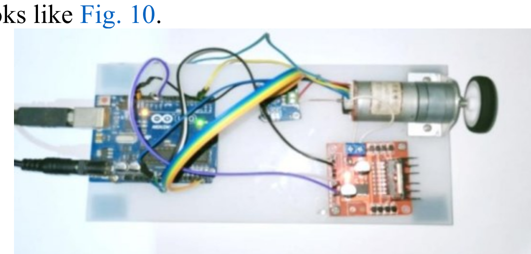

Fig. 10. Heart Rate and Oxygen Saturation Detection Device

The first experiment with 100 data samples, at the value of the constant 1 ($K1$) with 100 data samples, variation of the value of the constant 1 ($K1$) of 2, 3 and 4 was carried out, while the value of the other constants must be greater than zero (0) then $K2$ by 1 and KI by 0.1. If the gain is too large, then the system will take a long time to reach the steady-state state. Conversely, the gain is small in value then the output response is also small, so the controller becomes less responsive/sensitive, this situation will cause the controller response to be slower if it obstructs and can oscillate. Looks like Fig. 11.

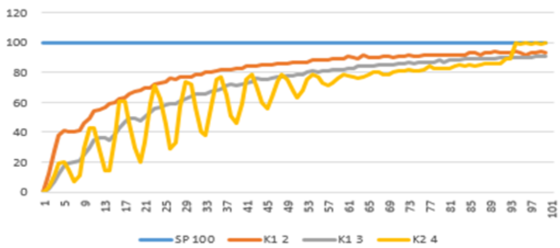

Fig. 11. First Attempt

In the second experiment with 100 data samples by varying the value of the constant 2 ($K2$) by 2, 3, and 4, while the value of the other constants must be greater than zero (0) then $K1$ by 1 and KI by 0.1. Predicting the nature of the system and further improving the residence time and stability of the system. Looks like Fig. 12.

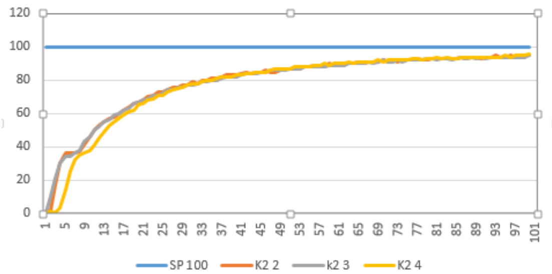

Fig. 12. Second Attempt

The third experiment with 100 data samples varied the value of the integral constant (KI) with values of 0.1, 0.5, and 1, while $K1$ and $K2$ must be greater than zero (0) then given a value of 1 each. Speeding up the move of the process towards the setpoint can lead to overshoot because the integral responds to the accumulated error than before. Looks like Fig. 13.

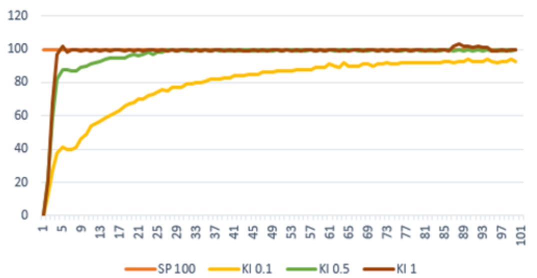

Fig. 13. Third Attempt

Variation of the values of the constants $K1 = 1, K2 = 2$, and $KI = 0.9$ the result of the system response is $tr\ (s) = 3$, $ts\ (s) = 4$, and $Os\ (\%) = 7\%$. Looks like Fig. 14.

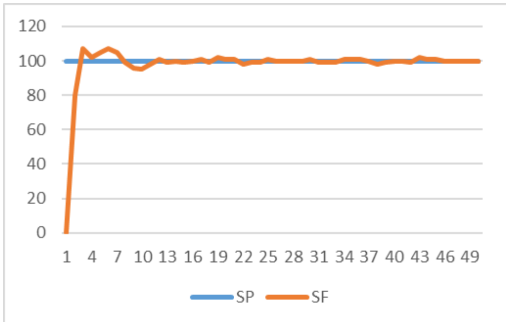

Fig. 14. Fourth Attempt

V. Conclusion

After observing the system response, the case of stability and speed in the response of the DC motor system can use the Integral State Feedback control system. The Trial and Error experiment on the system uses the best constant values are $K1 = 1, K2 = 2$, and $KI = 0.9$. The result of the system response is $tr(s) = 3$, $ts(s) = 4$, and $Os\ (\%) = 7\%$ so that the overshoot that occurs is not so large, and the rising time is short. Each constant value has an influence on the response of the system, adding an integral constant value (KI) affects the short rising time but is inversely proportional to the high overshoot value as well. Varying the values of $K1$ and $K2$ as multipliers on the sensor values has an impact on the stability of the system response or oscillations.

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