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BALANCE AND SPEED CONTROL SETTING ON *SEGWAY* UTILIZING PID CONTROL

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ABSTRACT
Segway is an innovation that utilizes an inverted pendulum model placed on top of a wheeled platform to create a transportation device capable of balancing itself. This research aims to investigate the balance and speed control settings on the Segway. The objectives are to address the balance issues of the Segway and determine the working system used. The study involves the analysis of components, circuitry, and mechanical design to overcome existing challenges. A BLDC (Brushless Direct Current) motor is employed to maintain the Segway's stability while in an upright position. An MPU-6050 sensor functions as a readout for the Segway's angle and position under various conditions. The control system used is Proportional Integral Derivative (PID). The PID method is applied using angle data from the MPU-6050 sensor to maintain balance on the Segway. This helps reduce errors and makes the Segway's movements smoother and more stable. In this research, the Segway can move after self-balancing with a maximum tilt angle of 30º. The PID values used are Kp = 48, Ki = 3.5, and Kd = 1.6.

Keywords: *Segway*, Sensor MPU-6050 , *Driver* BTS 7960, Kontrol PID.

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I. INTRODUCTION

The development of technology in the transportation sector is progressing rapidly, especially in land transportation (1). Traffic congestion occurs because the ownership of private transportation modes by the public exceeds the capacity of available roadways and can also be caused by simultaneous use of transportation modes. Besides causing traffic jams, it also results in air pollution (2). Therefore, Indonesia needs transportation devices that can alleviate congestion and minimize air pollution in the country, such as the Segway transportation device (3). To create a well-functioning Segway, attention must be focused on a robust mechanical system and the appropriate balance sensor program (4). The Segway combines three main components: sensors, microcontrollers, and actuators, which work simultaneously to maintain the robot's balance. This research aims to achieve a balanced Segway that can stand steadily with the driver using PID control (5).

The control method utilized in this research is the Proportional Integral Derivative (PID) control. PID has been widely used in various types of research and is relatively easy to implement (6). PID consists of proportional, integral, and derivative components, and this method can be used separately or in combination, depending on the desired response to the setpoint (7). PID was chosen as the suitable control system for this research as it can control the motor's movement to remain stable (8). This study aims to address the limitations of previous research that could not produce smooth movements of the Segway (9). In this research, BLDC motors are placed on the right and left sides to enable the Segway's movement on flat surfaces. The forces generated by the BLDC motors will interact with any disturbances that arise (10).

This research is expected to provide a breakthrough in the development of learning media as well as the implementation of the Segway.

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II. METHODOLOGY

A. MPU-6050

The MPU-6050 sensor is used as an input on the Segway to control its balance, as this sensor combines an accelerometer and gyroscope in a chip form with Micro Electromechanical System (MEMS) technology (11). To ensure the optimal functioning of the MPU-6050 sensor, the values of the X, Y, and Z axes are collected simultaneously at one time after being converted from the 16-pin analog format (12). The MPU-6050 sensor uses the inter-integrated circuit (I2C-bus) interface to connect with Arduino and has three rotation points (roll, pitch, and yaw) (13).

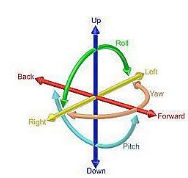

Figure 1. Rotation on the MPU-6050 Sensor

The MPU-6050 sensor functions as a continuous Attitude and Heading Reference System (AHRS) that calculates orientation but with less comprehensive representation compared to an MPU (14). Besides maintaining a 6-DOF motor's attitude, commercial MPUs also typically provide estimates of velocity and acceleration. This research requires a method to obtain the inclination or angle readings from the MPU-6050 sensor.

B. *Driver* BTS 7960

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The BTS7960 driver is one of the widely used motor drivers in component applications. It is the top choice for controlling high-current DC motors due to its exceptional durability and reliability (13). This motor driver has the capacity to handle currents of up to 43 amperes and can accept input voltage ranging from 5.5V to 27V.

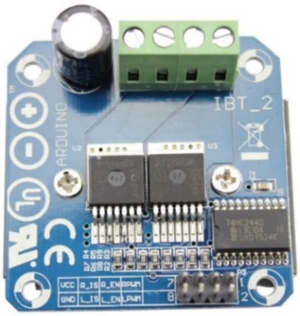

Figure 2. *Driver* BTS 7960

C. PID Method (*Proportional Integral Derivatif*)

The Proportional Integral Derivative (PID) control method is a controller designed to reduce the error level in a system, allowing the system to provide output signals with fast response, minimal overshoot, and low error rates(15). The purpose of using PID control is to minimize the error level that might occur in a system, thereby achieving the desired setpoint value. The parameters of the PID control are fundamentally based on the analysis of a system. Hence, no matter how complex a system is, it must be thoroughly understood before searching for the PID control parameters.

1. Proportional Control

Proportional control is a PID control that has an output signal that is proportional to the error level. The proportional output signal is the multiplication of a constant with the input signal. Proportional control utilizes two parameters, namely the proportional band that determines the controller's working range, and the proportional constant that indicates the error signal amplification factor (Kp) to generate the appropriate control signal. Proportional control is implemented using the following equation (1)

$$u(t) = Kp\ e(t) \quad (1)$$

Kp = Proportional constant
e = Error
u = Output value relative to time

2. Integral Control

Integral control is a control that functions to achieve a system response with a steady error level of 0. Integral control is expressed by equation 2 as follows:

$$u(t) = Ki \int e(t) d(t)\ t\ 0 \quad (2)$$

Ki = Integral constant
e = Error
u = Output value relative to time (t)

3. Derivative Control

Derivative control is a control that can correct the position of errors, but its response movement is not fast, requiring time. The control is expressed by equation 3 as follows:

$$u(t) = Kd\ de(t)\ dt \quad (3)$$

Kd = Derivative constant
e = Error

D. Electronics Design

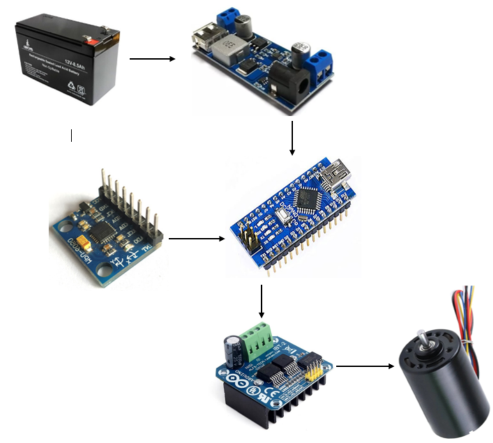

Figure 3. Electronics Design

The electronics circuit in the Segway begins with a 12-volt battery connected to a stepdown converter to lower the voltage to 5 volts. This 5-volt voltage is used as the power source for the Arduino Nano and MPU-6050 sensor. The Vin pin of the Arduino is connected to the (+) output of the stepdown, while the GND pin of the Arduino is connected to the (-) output of the stepdown. The stepdown is also connected to the battery through the (+) input pin of the stepdown and the VCC battery pin, as well as the (-) input pin of the stepdown and the GND battery pin (14).

The BTS7960 driver is used to control the PWM value in the Segway to drive the BLDC motor. Pins 5, 6, 9, and 10 of the Arduino Nano are connected to the data pins of the Arduino Nano, the 5V pin of the Arduino is connected to the VCC pin of the MPU-6050 sensor and jumpered with the BTS7960 driver, and the GND pin of the Arduino is connected to the GND pin of the BTS7960 driver.

E. System Block Diagram

A System Block Diagram is an illustration of the flow of a system, aimed at facilitating an understanding of how the system's processes work. In this system, a closed-loop control system is used, where there is a feedback process to minimize errors and make the system approach the desired output. The block diagram helps in identifying the components falling under categories such as setpoint, control input, PID, plant, and control output. The block diagram of the motorcycle robot balancing system is shown in Figure 4.

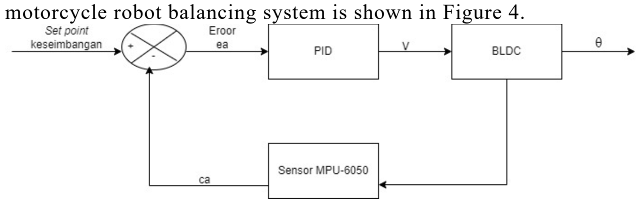

Figure 4. The system block diagram of the Segway device

The first process involves having a desired set point for balance. To obtain the balance error, it is controlled using the PID method. This results in a balance control variable that is controlled using BLDC (Brushless Direct Current) and produces a balance output, which is then compared with the balance sensor readings.

F. System Flowchart

The System Flowchart is an overview of the flow of the entire Segway system, designed to facilitate understanding of how the Segway system processes work. The first process involves initializing the device, which includes introducing parameters such as θs, θA, θ', V, and θ. Here, θs represents the set point angle, and θA is the angle read by the MPU-6050 sensor. θ' is the difference between the set point angle and the MPU-6050 sensor reading. V represents the output of the BLDC speed control obtained from the PID control, and θ is the output after plant control. After the initialization process, the next step is to read the MPU-6050 sensor data, which will then be processed by the PID control. Once the process with PID is complete, the speed will move according to its input. If the Segway is not balanced, the MPU-6050 sensor will read again. When the Segway achieves balance, the process will be completed.

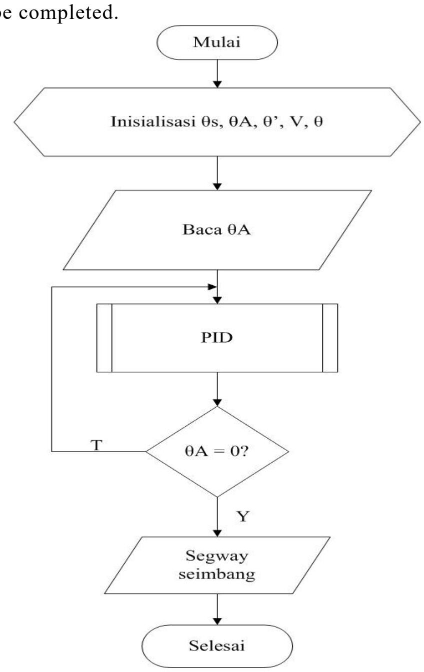

Figure 3. System Flowchart

G. PID Flowcart

The PID Flowchart is an illustration of the flow of the PID control system used to facilitate understanding of how the PID system works. A flowchart of the PID control system is created to make it easier to grasp the concept of the PID control applied in this research. PID is a control used for stabilization in the Segway. To obtain the desired setpoint value, the MPU-6050 sensor is used to read the inclination angle (θA).

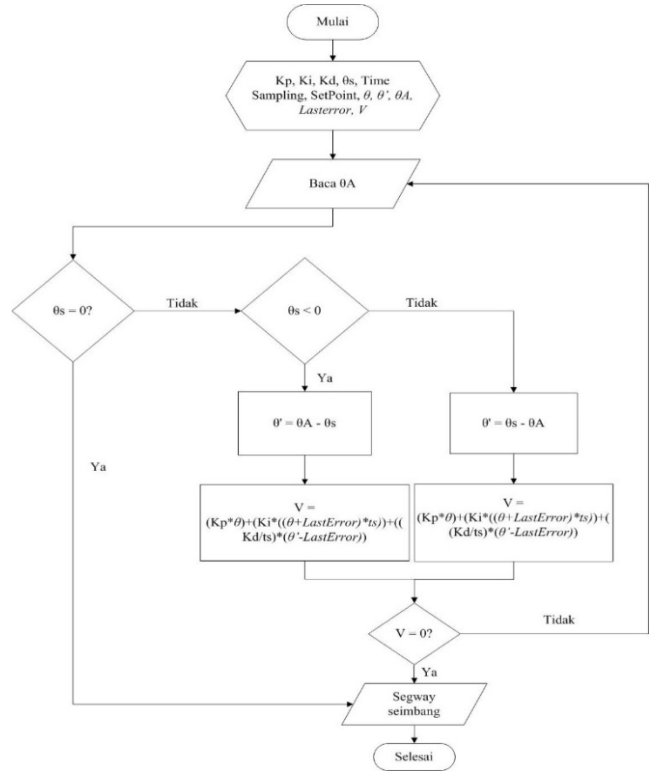

Figure 4. PID Flowchart

The first step is the process of recognizing Kp, Ki, Kd, θs, Time Sampling, θ', Last Error, and V. Then, it proceeds to read the value of θA. The process will be carried out under the condition where if the input is equal to 0. If it is true, then the value of θs is set to 0, and the Segway movement is balanced. If the angle value (θ) is less than 0, it will be processed by finding its error value, which is error (θ') equal to the input (θA) minus the set point (θs) as shown in equation 3.1.

$$\theta' = \theta_A - \theta_s \quad (3.1)$$

From the PID velocity calculation results, the desired outcome is that the right PWM value is equal to the right PID value. Similarly, in the condition where the angle value (θ) is greater than 0, the error value (θ') is equal to the set point (θs) minus the input (θA) as shown in equation 3.2.

$$\theta' = \theta_s - \theta_A \quad (3.2)$$

And the desired outcome is that the left PWM is equal to the left PID value. If the error (θ') is equal to 0, then V will be set to 0, and if not, the reading process will be repeated. The PID process is conducted to facilitate the configuration of reading values by minimizing the error level on the Segway, by finding the control output value (V) obtained from the PID process of the control input. Because PID can produce faster responses and smooth the movement of the Segway. The ultimate goal is to obtain a V value of 0. The process will repeat until the desired set point is achieved.

III. RESULT AND DISCUSSION

The result of making a segway equipped with a handlebar to keep the segway from falling when it is not in operation and when it is being used, as shown in Figure 5.

FIGURE 5. (A) FRONT VIEW (B) SIDE VIEW

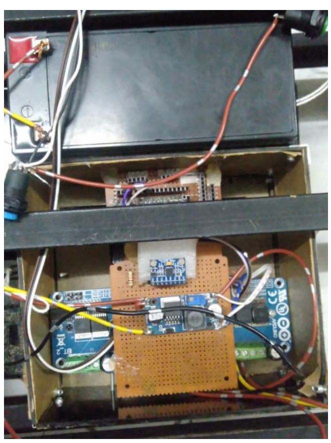

Figure 6. Components of the segway

The components used in the segway as seen in Figure 5 include (1) Arduino Nano, (2) MPU 6050, (3) Stepdown, (4) BTS 7960 Driver, (5) BLDC Motor, (6) Push Button, (7) Switch, and (8) Battery.

The mechanical design of this segway uses lightweight iron as the segway body with a base size of 45 x 27 cm, and iron with a size of 100 cm for its support material. The MPU 6050 sensor is placed at the center position of the base to ensure accurate angle readings. The BTS 7960 driver is placed on the left and right sides of the base. In this research, segway response testing is conducted using a PID controller, with the PID values tuned under both disturbance-free and disturbance-applied conditions.

A. Test Results with Kp 48, Ki 3.5, Kd 1.6, Ts 1

The testing was conducted with the segway being subjected to a slight push disturbance, as shown in the graph in Figure 7 below.

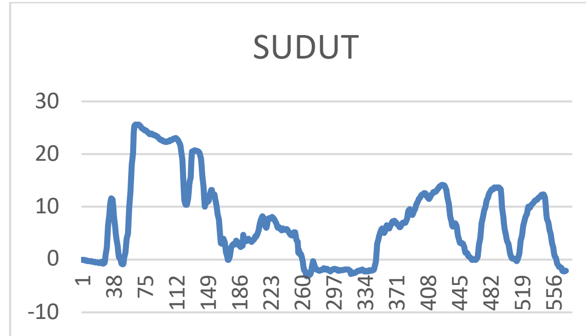

Figure 7. Segway condition with disturbance

This testing was conducted by providing a slight push disturbance from front to back, and the result was that the segway was able to balance itself.

The subsequent test was performed with the robot in undisturbed condition, as shown in the graph in Figure 8 below.

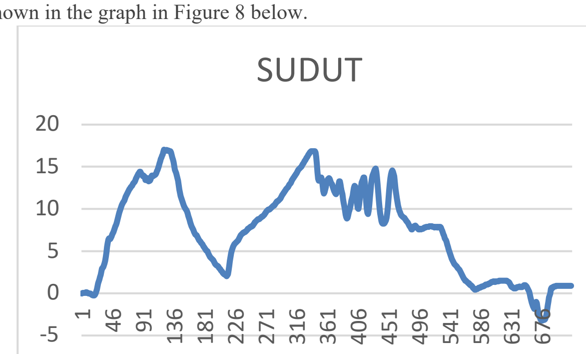

Figure 8. Robot condition without disturbance

In this test, the segway was operated without any disturbance, as depicted in the graph in Figure 4.24. It can be observed that the segway remains balanced in the undisturbed condition. Therefore, it can be concluded that in this test, the segway achieved a stable condition as expected.

4. CONCLUSION

Based on the research and testing conducted on this segway device, the following conclusions can be drawn:

1. The design and implementation of the PID control system for balancing the segway have been successful, with proven performance capable of returning the segway to the desired setpoint value through various tests.
2. The research results demonstrate that the system in the segway is now capable of balancing itself with the driver's control.

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