Ultrasonic Sensor Application As A Performance Enhancement Of Robot Two Wheels

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ABSTRACT

In this paper, Robot Two Wheels are developed further to improve performance or intelligence. A Robot Two Wheels is a robot that can move and balance itself on two wheels, maintain its position upright of the earth's surface on a flat plane. The design includes the Arduino Mega 2560, accelerometer and gyroscope sensors, as well as proportional Integral Derivative (PID) control as the controlling method. Proportional Integral Derivative control is used to determine the magnitude of the DC Motor's speed and rotary direction as the driver, based on the robotic body's tilt angle to the surface of the flat plane. The angle of inclination is taken into consideration and the robot moves either in the forward or backward direction to balance itself. When operated, the self-balancing robot continuously rotates its motor in its efforts to balance at upright position. The self-balancing robot movement is not mapped to its range, where the robot will still move randomly to achieve balanced conditions. The concept of this paper is expand the ability of the robot to sense objects around it which is by adding an ultrasonic sensor as an object detector around it, including obstacles or walls around self balancing robots. Detection of obstructions by ultrasonic sensors will maintain the movement of the robot in the safe area to avoid the impact that can occur when the robot is trying to maintain balance.

Keywords: self-balancing robot, robot two wheels, ultrasonic sensor, gyroscope, accelerometer, control PID

1. INTRODUCTION

A robot is designed in such a way and uses advanced technology. The robot must have a characteristic, good level of intelligence so that it can provide maximum performance and high artistic value and character [1] [2]. One way to increase the intelligence level of a robot is to add several sensors, therefore the number or the type of sensor will be used, expand the control system method, and even give artificial intelligence to the robot [3]-[6].
The navigation robot is one of the robots that have been widely designed by researchers, but usually, the mechanical design of the navigation robot uses three or more wheels, so that the balance setting of that kind of robot is not a vital problem [3] [4].

A two-wheeled balance robot is a mobile robot that has two wheels on its right and left side that can stand in balance with the settings of the controller. Usually, two-wheeled robots have a slight design, so the movements are more flexible and faster than three or more wheels [7]-[12].

This self-balancing robot or Robot Two Wheels design utilizes Arduino 2560 [13], accelerometer and gyroscope sensors [14], as well as proportional Integral Derivative (PID) control as a controlling method. Proportional Integral Derivative control is used to determine the magnitude of the DC Motor's speed and rotary direction as the driver [15], based on the robot's body tilt angle against the surface of the flat field so that the self-balancing robot can keep balanced against the earth's surface on a flat plane. [1] [2]. During operation, self-balancing robots constantly spin the bike in its effort to balance itself. The self-balancing robot movement is not mapped to its range, where the robot will still move randomly to achieve balanced conditions.

By adding an ultrasonic sensor [16], the robot will be able to detect objects surrounding it, including obstacles or walls that exist around the self-balancing robot. The detection of obstructions by the ultrasonic sensors will maintain the movement of the robot in the safe area to avoid the impact that can occur when the robot seeks to maintain balance [17]. There are various types of ultrasonic sensors used in the robotics system, one of which is HC SR-04 [16]. The sensor ultrasonic HC SR-04 is a sensor module that is widely used in the robotics system [11] [12]. The basic concept of this sensor is to utilize the principle of sound wave reflection that can be applied to calculate the distance of objects with the frequency specified according to the source oscillator [16] [17].

This paper discusses the application of the ultrasonic sensor as the main sensor of Robot Two Wheels to increase performance as a qualified self-balancing robot.

2. METHODOLOGY

Network Diagram block is one of the most important parts in designing a tool because, from the diagram block, this network can be known how the series works as a whole. So that the entire diagram block of the circuit will produce a system that can be enabled or can work according to the design. Figure 1 is a diagram block of Robot Two Wheels series using ultrasonic sensors.

![Figure 1. Block Diagram of Robot Two Wheels](image-url)

Description of the series block diagram in Figure 1 as follows:
1. The ultrasonic sensor HC SR-04 is a sensor used as an object detector or a barrier around the robot
2. The sensor MPU 6050 with 3 Axis Accelerometer + 3 Axis Gyroscope is the sensor used to detect the robot's tilt angle against the surface of the earth/floor
3. Arduino Mega 2560 as Controller center on the balancing robot
4. Motor Driver L298P as motor driver to move the DC motor right and left
5. Right motor and left Motor (DC 12v Motor) as drive system in balance robot

The electronic design of the Robot Two Wheels are consists of two sensors HC SR-04, sensor MPU 6050, Arduino Mega 2560, motor driver L298P, two DC Motors and Lipo battery, as shown in Figure 2.

![Electronic Circuit of Robot Two Wheels](image)

**Figure 2.** Electronic Circuit of Robot Two Wheels

In this paper in the design and assembly of software programs used for Robot Two Wheels is the Arduino IDE or Basic Compiler based on the basic language. Figure 3 shows the design of the size, layout, and shape of the robotic equipment itself. The mechanical design aims to protect the circuit from damage from outside the circuit while providing an aesthetic appearance of the created robot. Once the module installation process is complete then the next step is to design the body or casing in such a way.

The following is the design of the Robot Two Wheels body designs taking into consideration several things that are mechanical form, robotic size, and materials used.
Figure 3. Mechanical Design of Robot Two Wheels

3. RESULTS AND DISCUSSION

The real design result of the two-wheeled balance robot that has been created in this paper is shown in Figure 4. This research applies two ultrasonic sensors in front of and at the rear side of the robot.

Figure 4. Robot Two Wheels Front View
Figure 5. Rear Robot Two Wheels View

Figure 6. Robot Two Wheels Right Side View

Figure 7. Robot Two Wheels Left Side View

Testing of the gyroscope and accelerometer sensors aims to determine the level of accuracy of the sensors in reading the dynamic changing angles of the balancing robot. This Robot Two Wheels only require a tilt angle reading of about 35 ° to-35 °, so tests are only performed at 35 ° to-35 ° range with 5 increments.
Table 1. Accelerometer Tilt Angle Measurement Results

| NO | Sensor reading Angle Gyroscope and Accelerometer (Error) | PWM Output value | DC Motor Round Direction |
|----|---------------------------------------------------------|------------------|--------------------------|
| 1  | 5˚                                                      | 303              | CW                       |
| 2  | 4,5˚                                                   | 279.5            | CW                       |
| 3  | 4˚                                                      | 256              | CW                       |
| 4  | 3,5˚                                                   | 232.5            | CW                       |
| 5  | 3˚                                                      | 209              | CW                       |
| 6  | 2,5˚                                                   | 185.5            | CW                       |
| 7  | 2˚                                                      | 162              | CW                       |
| 8  | 1,5˚                                                   | 138.5            | CW                       |
| 9  | 1˚                                                      | 115              | CW                       |
| 10 | 0,5˚                                                   | 91.5             | CW                       |
| 11 | 0˚                                                      | 0                | Stop                     |
| 12 | -0,5˚                                                  | 91.5             | CCW                      |
| 13 | -1˚                                                    | 115              | CCW                      |
| 14 | -1,5˚                                                  | 138.5            | CCW                      |
| 15 | -2˚                                                    | 162              | CCW                      |
| 16 | -2,5˚                                                  | 185.5            | CCW                      |
| 17 | -3˚                                                    | 209              | CCW                      |
| 18 | -3,5˚                                                  | 232.5            | CCW                      |
| 19 | -4˚                                                    | 256              | CCW                      |
| 20 | -4,5˚                                                  | 279.5            | CCW                      |
| 21 | -5˚                                                    | 303              | CCW                      |
**Table 2.** DC Motor Rotation direction of the Gyroscope and Accelerometer sensors

| NO | Actual angle (protractor) | Output angle of Accelerometer Sensor |
|----|---------------------------|--------------------------------------|
| 1  | 35˚                       | 35,8˚                                |
| 2  | 30˚                       | 30,7˚                                |
| 3  | 25˚                       | 25,9˚                                |
| 4  | 20˚                       | 21,6˚                                |
| 5  | 15˚                       | 15,8˚                                |
| 6  | 10˚                       | 10,5˚                                |
| 7  | 5˚                        | 5,3˚                                 |
| 8  | 0˚                        | 0,8˚                                 |
| 9  | -5˚                       | -5,7˚                                |
| 10 | -10˚                      | -11,2˚                               |
| 11 | -15˚                      | -15,8˚                               |
| 12 | -20˚                      | -20,9˚                               |
| 13 | -25˚                      | -25,3˚                               |
| 14 | -30˚                      | -30,6˚                               |
| 15 | -35˚                      | -35,2˚                               |

Ultrasonic sensor testing aims to determine the level of accuracy of the sensor in reading distances in centimeters. This Robot Two Wheels can only avoid objects in a range of less than 18 centimeters, so testing is only done at 15 centimeters of object/barrier. Due to the speed of the sensor readings and the speed of motor rotation in a very fast unit of time, tests and measurements do not count in the millimeter unit but measured in centimeters.
Table 3. Distance measurement results readable by Ultrasonic HC-SR04 sensors

| Test | Actual distance (cm) | Distance detected by HC Sensor SR-04 (cm) |
|------|----------------------|------------------------------------------|
|      |                      | Front Sensor | Back Sensor |
| 1    | 1                    | 3            | 2           |
| 2    | 2                    | 3            | 2           |
| 3    | 3                    | 3            | 3           |
| 4    | 4                    | 4            | 4           |
| 5    | 5                    | 5            | 5           |
| 6    | 6                    | 6            | 6           |
| 7    | 7                    | 7            | 7           |
| 8    | 8                    | 8            | 8           |
| 9    | 9                    | 9            | 9           |
| 10   | 10                   | 10           | 10          |
| 11   | 11                   | 11           | 11          |
| 12   | 12                   | 12           | 12          |
| 13   | 13                   | 13           | 13          |
| 14   | 14                   | 14           | 14          |
| 15   | 15                   | 15           | 15          |

Installation of ultrasonic sensors affects the movement of robotic motors, where the output reading of the distance data can increase the speed of rotation of DC Motors in the robot as can be seen in the following Table 4.

Calculation of the object distance to the sensor is obtained from the length of time wave or 40 kHz frequency emitted by the oscillator to reach the receiver.
Table 4. DC Motor Speed Increase when the Robot is near the object

| NO | Angular reader Sensor Gyroscope and Accelerometer (Error) | Output PID Value | DC Motor Round Direction | Motor speed Increase | Distance to the Robot (cm) |
|----|----------------------------------------------------------|-------------------|---------------------------|-----------------------|--------------------------|
| 1  | 5˚                                                      | 303               | CW                        | -7                    | < 15                     |
| 2  | 4,5˚                                                    | 279.5             | CW                        |                       |                          |
| 3  | 4˚                                                      | 256               | CW                        |                       |                          |
| 4  | 3,5˚                                                    | 232.5             | CW                        |                       |                          |
| 5  | 3˚                                                      | 209               | CW                        |                       |                          |
| 6  | 2,5˚                                                    | 185.5             | CW                        |                       |                          |
| 7  | 2˚                                                      | 162               | CW                        |                       |                          |
| 8  | 1,5˚                                                    | 138.5             | CW                        |                       |                          |
| 9  | 1˚                                                      | 115               | CW                        |                       |                          |
| 10 | 0,5˚                                                    | 91.5              | CW                        |                       |                          |
| 11 | 0˚                                                      | 0                 | Stop                      | 0                     | 0                        |
| 12 | -0,5˚                                                   | 91.5              | CCW                       |                       |                          |
| 13 | -1˚                                                     | 115               | CCW                       |                       |                          |
| 14 | -1,5˚                                                   | 138.5             | CCW                       | +7                    | < 15                     |
| 15 | -2˚                                                     | 162               | CCW                       |                       |                          |
| 16 | -2,5˚                                                   | 185.5             | CCW                       |                       |                          |
| 17 | -3˚                                                     | 209               | CCW                       |                       |                          |
| 18 | -3,5˚                                                   | 232.5             | CCW                       |                       |                          |
| 19 | -4˚                                                     | 256               | CCW                       | +7                    | < 15                     |
| 20 | -4,5˚                                                   | 279.5             | CCW                       |                       |                          |
| 21 | -5˚                                                     | 303               | CCW                       |                       |                          |
Table 1 and Table 2, shows that the accelerometer sensor still has errors, this can be caused by less precise measurements, rounding fractions in the programming and noise generated by the sensor itself. According to the table above, it is known that the greater the angle of reading of the gyroscope sensor and the accelerometer (error) will be the larger output generated by the calculation of PID.

Calculation of the output PID obtained from the formula:

$$Output = kp*error + ki*errSum + kd*dErr$$

Where :

- **Kp**: Value of proportional constants
- **Error**: Sensor reading value of gyroscope and accelerometer
- **Ki**: Integral Constant value
- **errSum**: error* Time change
- **Kd**: Derivatives constant values
- **dErr**: (error – Previous error) / Time change

The result of the PID output value may exceed the value of 255 whereas the PWM motor value can only run the maximum at the value of 255. For that, if the output PID value exceeds the maximum PWM limit value then the PWM output to the motor will still be considered the maximum value of 255.

Ultrasonic sensors installed in the robot are 2 pieces, where if the sensor reads the object in front or behind the robot as far as < 15 cm, the Arduino will instruct the DC motor to rotate counterclockwise towards the object and increase the speed at PWM Motor so that the robot moves away from the object or barrier.

At the time of testing it was shown that overshoot was produced due to substantial proportional control so that when it turned around, the robot was difficult to get a balancing angle. To reduce overshoot generated by proportional control then added derivative control.

In Table 2 overshoot generated by proportional control can be minimized by adding the control of the derivative into the system. Once the derivative controller is added to the system than to make the movement of the robot more smooth or decrease the steady-state error there will need to be added an integral controller to the system.

It can be seen in Table 3 balance robot can reach the angle of the hole in the angle range 5 ° to -5 °. The value of controller constants included in the robot control system is obtained from the results of a trial error method using the Potentiometer. The trial error method done using the Potentiometer is to connect 3 pieces of potentiometer on the Arduino, all three of these potentiometers as input to determine the value of KP, KI, and KD in the robot. After the trial error has been made a smooth robot movement then the three potentiometers can be removed, then the constant P, I and D obtained from the error trial results can be inserted into the program control robot system.

A PID controller created on a balance robot system is used to retain the robot in its position, using inputs from the gyroscope and accelerometer sensors, then the system calculates the magnitude of the PWM value used to Turn the DC motor as output to balance the robot. It can be seen in Table 2 as sample when the input value of the gyroscope is worth 0.5 with the constant value P = 46, I = 0.2, D = 680 Then the system will calculate the output to move the DC motor in the direction of clockwise with PWM of 91.5. As the robot's tilt angle increases (error) as input on the PID control the output generated by the system will be greater.

While maintaining its balance, the robot will continuously move back and forth without direction. By adding two ultrasonic sensors on the front and back, the robot can read nearby objects so that when the robot maintains its balance and there is an object too close to it, the Arduino will order the motor DC to rotate counterclockwise with the object.

The maximum distance to the object arranged on the robot is 15 cm so if there are objects with a distance of < 15 cm on the front and rear, then the robot will try to avoid it by giving PWM output on
the DC motor of +7 if the object is in the Rear of the robot and -7 if the object is on the front of the robot, assuming if the tilt angle is valued + we consider the robot to point to the front and if the slope angle is worth – then the robot leads back to the rear. If the robot maintains its balance when the sensor tilt angle is valued + where the robot is pointing forward then the robot will instruct the DC motor to rotate the opposite direction to the robot's fall direction, at the same time if the robot reads there Object in front of it with a distance of < 15 cm then the robot ordered to increase PWM speed to avoid the object.

Thus, when the Two-wheeled Balance Robot is moving to maintain its balance, the robot can detect objects with a distance of < 15 cm, moving counter clockwise to avoid them so that the robot can prevent collisions with objects or obstructions surrounding it.

4. CONCLUSIONS

This paper discusses and analyzes the ability of the Robot Two Wheels to detect objects around it while the robot is moving to regulate its balance to remain upright against the earth’s surface. With a constant value of P = 35, I = 0.2, D = 680, the robot can maintain its balance in the angle range between 5° to -5°. The placement of the MPU 6050 sensor must be in the middle position of the robotic body and positioned at the highest in the robot body for precise sensor accuracy. The maximum distance to the robot's regulated object is 15 cm, where the robot attempts to avoid objects or obstructions by giving PWM output to a DC motor of +7 on the rear ultrasonic sensor and -7 if the object is in the ultrasonic sensor of the front of the robot. When the ultrasonic sensor detects an object or barrier at the front and back of the robot, the DC motor rotates in the opposite direction away from the object to avoid collisions so that the robot remains in its safe position. Thus the Robot Two Wheels has the advantage of being able to defend its position and can detect the surrounding objects to avoid the impact when the robot moves.

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