Design of Bicycle’s Speed Measurement System Using Hall Effect Sensor

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Abstract. Bicycles are an easy-to-use and affordable transportation tool for all society. However, in cycling, there is no information about the speed and distance that has been taken. Whereas, these parameters are quite essential because knowing that we can adjust the speed of the bicycle if we are going to the office or school so that we can estimate the time of arrival to reach the destination. Commonly, the device used to measure the speed and distance of a bicycle is a device with a GPS feature as a system based on geographical location. However, this device measures speed by knowing the position of the user captured by the satellite, not resulting from the actual speed of a bicycle. In this research, the designed system can measure the actual speed of a bicycle using the rotational speed of a bicycle wheel. The system implemented by using the Hall Effect sensor that will detect the magnet. The microcontroller then processes the data and convert the rotation per second into linear velocity. Then, information on speed, distance, and average speed are displayed to the LCD screen. After testing and analyzing the bicycle speed and distance measuring system using the Hall Effect sensor, we can conclude that The speed and distance of a bicycle can be measured by the hall effect sensor with the number of rotations that the Hall Effect sensor can detect up to 542 revolutions/minute. The final results of speed and distance can be displayed on the LCD, with the percentage error 2-3%.

1. Introduction

Bicycles are an easy-to-use and affordable transportation tool for all society. As a means of transportation, bicycles are often used to go to work or school. The use of bicycles also affects the surrounding environment which does not pollute the air like motor vehicles. Besides, bicycles can also be used as a means of relaxing sports, as well as strenuous exercise such as a bicycle race that requires more energy. However, in cycling, there is no information about the speed and distance that has been taken. Whereas, these parameters are quite essential because knowing that we can adjust the speed of the bicycle if we are going to the office or school so that we can estimate the time of arrival to reach the destination [1].

Commonly, the device used to measure the speed and distance of a bicycle is a device with a GPS feature as a system based on geographical location. The speed and time needed by the user can be determined by the received data from the satellite [2]. However, this device measures speed by knowing the position of the user captured by the satellite, not resulting from the actual speed of a bicycle. Related work has been conducted in bicycles speed measurement research. In a study [3] a batteryless sensorless bicycle speed recorder system with a hub dynamo that functions as both a power source and a speed sensor has been developed. However, the system only records speed and acceleration. Another
research [4], consider using a low-cost ultrasonic distance sensor for monitoring the road surface condition in the front area of the bicycle. Then, a study introduced a bicycle record system of ground conditions based on IoT which is combining smartphone and embedded system [5]. This system can only function in an area with internet coverage. Thus, in this research, the designed system can measure the actual speed of a bicycle using the rotational speed of a bicycle wheel. The system implemented by using the Hall Effect sensor that will detect the magnet. The microcontroller then processes the data and convert the rotation per second into linear velocity. Then, information on speed, distance, and average speed are displayed to the LCD screen. The contribution of this research work is to give cyclists information of speed, distance, and average speed so that users can predict the speed that must be obtained in order to reach the destination within a certain amount of time.

2. System Design

The general design of the system as shown in Figure 1 is a bicycle that has been affixed with a piece of magnet to the tire. Hall Effect sensor then attached closer to the suspension fork so that it can read the magnet when the wheel rotates. Furthermore, to convert the rotation speed of the bicycle wheel, a hall effect sensor [6] is connected to the microcontroller (Arduino Uno). The designed program must be able to convert angular velocity to linear speed accurately and determine the speed and distance of the bicycle. The conversion results will be displayed on the LCD [7]. The final result is determined based on how quickly or slowly the user pedals the bicycle. The size of the wheel used in this research is 26 inches or 66 cm.

![Figure 1. System Design](image)

A. Hardware Design

The speed and distance measuring system of a bicycle uses a hall effect sensor by detecting a magnet that moves in a circle. The hardware design of this system is as shown in figure 2 below. Hall Effect sensor then connected to Arduino Uno to process the conversion of the rotational speed of bicycle’s wheel to linear speed. Results then show in LCD Display.

![Figure 2. Hardware Design](image)
B. Software Design

Software design is done by specifying system functionality, starting from reading data from the Hall Effect sensor. If a magnet is detected by a sensor, the system will start the conversion process by sending data to Microcontroller. The received data then used as input for calculating three aspects, that is bicycle speed (km/h), distance traveled (km), and average speed (km/h). These three data outputs will then be displayed on the LCD. The following figure 3 show pseudo code of the system algorithm for bicycle speed measurement.

```
Algorithm 1 Bicycle Speed Measurement
1. function setup(sensor) ▶ Activate Hall effect Sensor
2. System Initialization
3. Read the value
4. sensor = detect + 1 ▶ count sensor detection
5. function measure RPM(speed, distance, average) ▶ Calculate RPM
6. while sensor ≠ 0 do
7.   speed = \( \pi \times \frac{d}{\text{periods}} \) ▶ speed in (km/h)
8.   distance = \( \text{impulses} \times \pi \times \text{diameter} \) ▶ distance in km
9.   average = distance \( \div \) times ▶ average speed (km/h)
10. return speed, distance, average
11. return sensor
```

Figure 3. Bicycle Speed Measurement Algorithm

3. Results and Discussions

In this sub-chapter, we will discuss how to implement the hardware and software design to the actual system. The implementation phase is divided into three namely the implementation of hardware (hardware), the implementation of software (software) and the implementation of the system as a whole. Hardware implementation is the stage of making the physical form of the system. The software implementation is a program designed to be able to read and detect sensors to be able to determine the speed and distance traveled. While the implementation of the system aims to determine whether the system created can run well and can achieve the objectives of the study. Furthermore, planning the testing actions to be taken and collect the data that must be obtained from the hardware and the system as a whole when the system has been implemented. Tests are carried out on the Hall Effect sensor to test the detection ability of the magnet. The microcontroller then calculates the maximum and minimum distance between the magnet and the sensor so that the reading is more accurate. To find out the rotating speed based on the magnetic rotation on the bicycle wheel.

A. System Implementation

On the implemented hardware there is a hall effect sensor that is used as input from the system to detect magnets on the bicycle wheels in order to determine bicycle speed, average speed, and distance traveled. The speed and distance that has been obtained are then displayed on the LCD as information to the user. To process the input data, the Microcontroller communicates with the Hall Effect sensor through I/O port. Additionally, I2C serial communication interface is used to facilitate communication between the microcontroller and LCD. The software implementation of this system uses the Arduino IDE [8]. An interrupt method is implemented by using the attachInterrupt function. The interrupt is used as a function to trigger the hall effect sensor. When the Interrupt is triggered, the interrupt program will stop the program that is running for a moment and carries out the interrupt program. In the interrupt function, there are four types of conditions. Namely, the condition of Low, Change, Rising and Falling. The situation used in the implementation of this software is the interrupt with the Rising state, where the interrupt program will be carried out if the trigger changes logic from a low to high state. The implementation of the system on this bicycle as shown in figure 4 is tested on a flat road, and there are no obstacles that can make the system shock. The system will measure the speed and distance of the bicycle by detecting the magnet on the radius of the bicycle wheel.
At this stage, system testing and analysis will be carried out in terms of hardware, software, and overall system testing.

1) Hall Effect Sensor Testing

Hall Effect sensor testing is done to ascertain how much distance is needed between the magnet and the sensor so the system can run properly. Testing is done by measuring the distance of the magnetic reading by the Hall Effect sensor by using a ruler. The values of different voltages are obtained based on the distance taken from the magnet to the sensor as in table 1.

**Table 1.** Testing Results of Hall Effect Sensor

| No. | Magnetic Distance to Sensor (cm) | Voltage (mV) |
|-----|---------------------------------|--------------|
| 1   | 0                               | 881          |
| 2   | 1                               | 578          |
| 3   | 2                               | 504          |
| 4   | 3                               | 496          |
| 5   | 4                               | 494          |
| 6   | ≥5 (without magnet)             | 492          |

From the tests obtained, the sensor can detect magnets up to a distance of 4 cm with a voltage value of 494 mV which is displayed on the serial monitor. By testing the sensor, it can be seen that the closer the magnet is to the sensor, the higher the value of the voltage, while the farther the magnet from the sensor, the smaller the voltage value. The comparison value will change otherwise if the pole changes the magnet which is brought closer to the sensor because each magnet has two different poles. The value of the voltage generated from the sensor also depends on the strength of the magnetic attraction and the type of magnet used. The magnetic distance to the sensor used in this system is 2.5 cm. Testing of the hall effect sensor is also done by measuring how fast the sensor can detect magnets as in Table II. In this test, we measure the number of times the sensor takes to detect every magnet that passes through it. So that by knowing this, it is acquired how quickly the magnet passes the detection response from the sensor with the speed of rotation of the bicycle wheel. From the detection time testing, the Hall Effect sensor can detect magnets with an interval of 101 to 111 ms for each detection, with a testing time of up to 60 seconds and many rotations obtained reaching ± 542 revolutions/minute. This test is done to find out how fast the sensor can respond to the magnet that passes through it.
Table 2. Detection Time of Hall Effect Sensor

| No. | Time (s) | Number of Rotation | Detection Time / Rotation (ms) |
|-----|----------|--------------------|-------------------------------|
| 1   | 10       | 92                 | 107-110                       |
| 2   | 30       | 284                | 101-109                       |
| 3   | 60       | 542                | 108-111                       |

2) Software Testing

Software testing is done by focusing on the interrupt program that will be used on the system. The interrupt testing program aims to get the sensor detection results accurately so that the sensor will appropriately detect each magnet passed by the sensor by using the interrupt method on the designed program. The interrupt program is used to trigger the sensor on the system so that when the interrupt program is triggered, the interrupt program will stop the program that is running for a moment and carry out the interrupt program. This interrupt program is initialized by using the "attachInterrupt (0, magnet_detect, RISING) syntax;". From the syntax it is known that 0 is the first interrupt pin, which is pin two on Arduino, magnet_detect is a function variable to call the program, and RISING is the interrupt mode used. When an interrupt is triggered, the program will immediately stop the running program and call the magnet_detect function on the interrupt program. So that by using the interrupt, the sensor can quickly read the magnet that passes through it. Magnets can be detected quickly and accurately because it uses an interrupt program without causing delay or other programs that are running.

3) Overall System Testing

Overall system testing is conducted to find out whether the system that has been designed works properly. Starting from the process of reading the magnet to the Hall Effect sensor on the bicycle wheel and turning it into the speed, distance, and average speed of the bicycle. Therefore, the information can be displayed on the LCD for the convenience of the user.

To get the final value of the speed, distance, and average speed from the rotation of the bicycle wheel there are several parameters that must be considered. (1), the diameter of the bicycle wheel to find out the circumference of the bicycle wheel, (2), the period as the time needed to reach one cycle of bicycle wheel’s rotation, then (3) linear velocity from the rotation of the wheel [9],[10],[11]. Moreover, the system can calculate the distance traveled by bicycle based on the number of rotations of the bicycle wheel.

Bicycle speed can be calculated by the following equation:

\[
\text{Speed (km/h)} = \frac{\text{wheel's circumference (km)}}{\text{period (h)}}
\]

Where, wheel’s circumference = \( \pi \times d \). Then :

\[
\text{Speed (km/h)} = \frac{\pi \times d \text{ (km/h)}}{\text{period (h)}}
\]

The distance traveled by bicycle can be calculated by the following equation:

\[
\text{Distance (km)} = \text{impulse} \times \pi \times d \text{ (km)}
\]

Where, \( \text{impulse} \) = the number of rotations of the bicycle wheel.

Thus, the average speed of the bicycle can be calculated by the following equation:

\[
\text{Average Speed (km/h)} = \frac{\text{distance}}{\text{times}}
\]

Where, \( \text{times} \) = total cycling time.

Testing is done with flat road conditions, where there are no disturbances such as road bumps and in good weather condition. While testing is conducted, the speed value that shows in LCD changes according to the speed of the bicycle. Therefore, when the bicycle is fast pedaled, the value of the speed displayed will change to a higher value. Conversely, as the stroke of the bicycle is slowed, the speed value displayed will be smaller. The average speed that is displayed on LCD is based on the distance the trip has passed. To ensure the distance obtained by the actual distance, we use the markers of road distance from one city to the closest one that is placed on the edge of the road as in figure 5.
When testing the distance, the initial position is set on the road marking which shows the sign of PDG 74, which means that the city of Padang is 74 km from the position of the road mark, with the value of the distance on the 0.00 km system. After the bicycle is ridden to the next road markings, namely with the sign PDG 73, which means the distance that has been traveled as far as 1 km, the system also displays a value of 1.00 km. So that from this test we can conclude that the system is able to calculate the mileage value according to the actual distance. For the overall test data that has been conducted can be seen in the following table III. The table shows the test data on the overall system which includes distance, changes in speed, average speed, and travel time.

| No. | Distance (Km) | Speed (km/h) | Period (h) | Average Speed (Km/h) | Times          |
|-----|---------------|--------------|------------|----------------------|----------------|
| I   | 1.00          | 1.10         | 0.001818   | 12.19                | 4 m 49 s (289 s) |
|     | 5.65          | 0.000354     |            |                      |                |
|     | 9.78          | 0.000204     |            |                      |                |
|     | 12.02         | 0.000166     |            |                      |                |
|     | 11.08         | 0.000181     |            |                      |                |
|     | 12.00         | 0.000167     |            |                      |                |
|     | 12.02         | 0.000166     |            |                      |                |
|     | 12.00         | 0.000167     |            |                      |                |
|     | 12.02         | 0.000166     |            |                      |                |
|     | 11.10         | 0.000180     |            |                      |                |
| II  | 1.04          | 1.53         | 0.001307   | 16.67                | 3 m 40 s (220 s) |
|     | 5.64          | 0.000355     |            |                      |                |
|     | 9.17          | 0.000218     |            |                      |                |
|     | 10.48         | 0.000191     |            |                      |                |
|     | 12.02         | 0.000166     |            |                      |                |
|     | 13.10         | 0.000153     |            |                      |                |
|     | 14.43         | 0.000139     |            |                      |                |
|     | 17.63         | 0.000113     |            |                      |                |
|     | 16.02         | 0.000125     |            |                      |                |
|     | 15.98         | 0.000125     |            |                      |                |

From the test data table, it appears that the speed displayed on LCD changes; this occurs because of variations in bicycle pedaling by the user. Erratic speed changes occur when the bicycle passes the road bumps. The situation happens because the bicycle wheels get a shock which causes the sensor not correctly detecting the magnet. The variation of speed as shown in the graph is the result of distance.
traveled by 1.00 km. The average speed obtained in this first experiment is 12.19 km/h and the travel time is 4 minutes 49 seconds. We compare the results that the system obtained with the actual speed calculated manually using a formula with the same data. It was found that the measurement system has worked well even though there are slight differences. With the percentage of errors acquired in the testing were 2.16%, 2.11%, 3.34%, 3.10% respectively for four testing trials as shown in Table IV.

Table 4. Percentage of Galat in The System

| Testing Trials | I     | II    | III   | IV    |
|----------------|-------|-------|-------|-------|
| Distance (km)  | 1.00  | 1.04  | 1.01  | 1.00  |
| Times (s)      | 289   | 220   | 272   | 258   |
| Average Speed  |       |       |       |       |
| (system) (km/h)| 12.19 | 16.67 | 12.92 | 13.52 |
| Average Speed  |       |       |       |       |
| (manual) (km/h)| 12.46 | 17.03 | 13.36 | 13.95 |
| Speed Difference (Km/h) | 0.27 | 0.36 | 0.447 | 0.433 |
| Error (%)      | 2.16  | 2.11  | 3.34% | 3.10% |

4. Conclusions
After testing and analyzing the bicycle speed and distance measuring system using the sensor hall effect, we can conclude that (1). The hall effect sensor can be implemented as a speed sensor. (2). The speed and distance of a bicycle can be measured by the hall effect sensor with the number of rotations that the Hall Effect sensor can detect up to 542 revolutions/minute. (3). The final results of speed and distance can be displayed on the LCD, with the percentage error 2-3%. The designed system has contributed to give cyclists information of speed, distance, and average speed so that users can predict the speed that must be obtained in order to reach the destination within a certain amount of time. For further work, we will try to compare the calculations with GPS sensors that use Earth's coordinate points.

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