Design A Low Cost Wind Direction Sensor With High Accuracy

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***Abstract*—Wind is an important component that is beneficial to human life. For example, wind direction affects the landing and takeoff of an aircraft, wind helps fishermen for steering the boat while looking for fish. Wind can also be used as an alternative energy source that is environmentally friendly. Because of the importance of wind components, a device that can measure the wind parameters in a certain place is needed. Therefore, this study tries to create a cheap wind direction sensor which can be utilized by many people.**

In previous studies, reed switches, rotary encoders, and potentiometers have been used to create wind direction sensors. But this wind direction sensor has several weaknesses such as, it is not accurate, it has expensive production costs, and it has some friction that will strive against the movement of the wind, so it takes a minimum wind speed value for the wind direction measuring instrument to work. From these weaknesses, this study attempts to create wind direction sensors using other method namely light intensity method.

This method used only a small LED light source with a Photodiode sensor, and a rotary disk. Test results indicated that this wind direction sensor had a mean of measurement error of 0.62% and the production cost of this wind direction sensor was only 50.300 rupiah or only about 3.5 US Dollar. From the value it can be concluded that the wind direction sensor made in this study was very well used to measure wind direction that occurred in a certain place and it could be produced with very cheap cost.

Keywords—LED, Low Cost, Photodiode, Wind Direction Sensor

I. Introduction

Wind is the air that moves from area that has low temperature to area that has high temperature [1]. The equator are which is an area located at 0° latitude is warmer than other regions on Earth. This causes the temperature at the equator to be higher than the temperatures in the subtropics or the polar regions. In areas with higher air temperatures, the air is expanding so as to make the air pressure lower. In areas with lower air temperatures, air pressure becomes higher. This air pressure difference will make air movement from areas with high air pressure to areas with low air pressure. Heat transfer that occurs through a moving air medium is called convection.

Actually the temperature difference occurring in some areas of the earth's surface is due to the uneven radiation reception of the sun on the surface of the earth [2]. Uneven radiation reception makes the wind conditions in certain areas are difficult to predict. Whereas wind direction greatly affects the landing and takeoff of aircraft [3]. Pilots will tend to land or take off in the direction of the wind. Wind speed also affects the construction of wind power plants [4]. The faster the wind blows in an area, the greater the electrical energy obtained. Wind speed and wind direction are also frequently used in meteorology and geophysics for weather forecasts [5]. Weather forecasts are also very important for farmers and fishermen to know the right time to grow crops or to go to sea. Because of the importance of the wind components, a device that can measure the wind parameters in a certain place is needed. Therefore, this study tries to create a measuring instrument that serves to measure one of the wind parameters i.e. wind direction.

There were many studies that have been conducted in the creation of wind direction sensors. Some studies used reed switch to detect wind direction [6]. The reed switch utilizes magnets placed on the disk. This magnet is placed in several positions that represent all the directions of the wind. The weakness of this method is that the sensor can read only 8 point of wind direction (north, northeast, east, southeast, south, southwest, west, northwest). This method needs sensor component such as 8 reed switches (Rp.16.000) and 8 resistors (Rp.400), so that it spends about Rp. 16.400 ($ 1.14) for only the sensor parts not including the mechanical part.

Another method is applied in several studies for making wind direction sensor [7]. This wind direction sensor utilizes a rotary encoder to detect wind direction. The rotary encoder used has either absolute or incremental types. This rotary encoder has a hole per certain degree position. The advantage of this method is that the wind direction can be read although wind direction is not at the 8 points of the compass. The more holes, the smaller the readability of the wind angle can be. The disadvantage of this method is that the sensor has an expensive price, especially the absolute rotary encoder type since the production process of this sensor requires high precision. On the market, the price of rotary encoder which can read 36 point of wind direction almost reach Rp. 75.000 ($ 5.2). This price is only for the sensor parts not including the mechanical part.

The use of potentiometer has also been tested to measure wind direction [8][9]. This sensor is used to measure wind direction by utilizing potentiometer rotation. The wind will rotate the potentiometer in a certain direction. This potentiometer rotation results in resistance with certain values. The resistance value is converted into an analog voltage value. This analog voltage is directly proportional to the rotation angle of the potentiometer. This device can measure the wind direction very well, since a bit of potentiometer movement has different voltage values. The weakness of this method is the friction that occurs in potentiometers that will strive against the movement of the wind, so it takes a minimum wind speed value for the wind direction measuring instrument to work. In order to read wind direction up to 360 degrees, the type of potentiometer is multiturn potentiometer. On the market, it costs about Rp. 37.000 ($ 2.56). This price is only for the sensor parts not including the mechanical part.

From the existing studies, this study would refine the wind direction sensors by eliminating the weaknesses in the existing wind direction sensors. So the wind direction sensor that produced by this research is expected to measure wind direction from various angles, without causing friction and does not require expensive costs in the production process.

II. Hardware and Software

A. Hardware

Basically the method used to read wind direction angle values is light intensity method. This method requires 2 types of hardware namely circuit hardware and wind direction sensor hardware. The circuit hardware consists of microcontroller, Photodiode, and LED, while the wind direction sensor hardware consists of a rotary disk, and a stainless steel arrow. The components used in this wind direction sensor are as follows:

1) Microcontroller

Microcontroller is a chip that functions as an electronic circuit controller and generally can save programs in it. The microcontroller consists of a CPU (Central Processing Unit), memory, several I/O and supporting units such as Analog-to-Digital Converter (ADC) which are integrated in it. The microcontroller has various types. In this study, the type of microcontroller is Atmega328. The pin configuration on ATMega328 can be seen below.

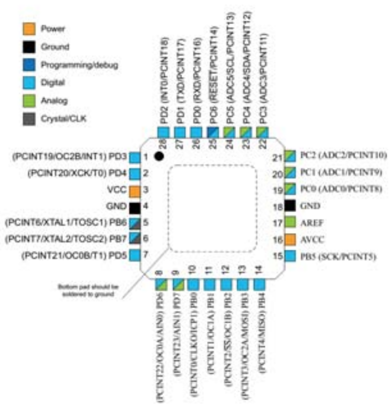

Fig. 1. ATMega328 Configuration [10]

ATMega328 is a type of microcontroller that has a RISC (Reduction Instruction Set Computer), architecture that has the advantage of faster data execution than the CISC (Completed Instruction Set Computer) architecture. ATMega328 has 3 main PORT namely PORTB, PORTC, and PORTD with a total of 23 pin input/output pins. These ports can be functioned as digital input/output or functioned as other peripherals.

ATmega328 uses 5V voltage to operate. Besides being used to activate the microcontroller, the voltage of 5V is also used for photodiode and LED circuits. Therefore, a regulator circuit is needed to activate this circuit. The pin that used on this sensor is only 3 pins which are pin 3 (VCC), pin 4 (GND), pin 19 (PORTC0). Pin 3 and pin 4 will be connected to the regulator circuit. While pin 19 is an ADC (Analog Digital Converter) pin that is used to convert the analog voltage values from photodiodes to digital values. This digital values will be processed into the microcontroller which will be converted into wind direction angle values.

2) Photodiode

Photodiode is a type of diode made of semiconductor material where the resistance will change when exposed to light from outside environment. Semiconductor materials often used in the manufacture of diodes are Silicon (Si) or Gallium Arsenide (GaAs) materials. In addition, there are several other materials used in the manufacture of diodes namely Indium Antimonide (InSb), Indium Arsenide (InAs), Lead Selenide (PbSe), and Tin Sulfide (PBS). Photodiode has two legs, namely Anode and Cathode. Photodiode often uses in reverse biased configuration.

The resistance of Photodiode is affected by the intensity of the light that it receives. The more light that received by Photodiode, the smaller resistance value of Photodiode, and vice versa, if the less light intensity that received by Photodiode, the greater resistance value of Photodiode [11]. This component was utilized in this wind direction sensor. Each wind direction angle, the Photodiode must be made to receive different light intensity. Different light intensity will produce different Photodiode voltages. The voltage will be converted to a wind direction angle. The photodiode used in this study has 3 mm diameter that can be seen below.

Fig. 2. Photodiode [12]

3) LED (Light Emitting Diode)

LED or Light Emitting Diode is one type of diode that can emit light [13]. Light colors emitted by LED depend on the type of semiconductor material its use. Just like Photodioda, LED also has two legs namely Anode and Cathode. The way the LED works will only emit light when it receives forward bias current. LED consists of a dopped semiconductor chip that creates P and N junctions. The doping process in semiconductors is a process to add impurities to a pure semiconductor resulting in desirable electrical characteristics. When the LED is receives forward bias current from the Anode to the Cathode, the excess electrons in the negatively charged region will move to the excess hole region in the positively charged region. When an electron meets the hole it releases the photon and emits monochromatic light. Each type of monochromatic light color has a different forward bias voltage. The smallest forward bias voltage is red while the highest forward bias voltage is white. In this study, the LED used is a red LED of 3mm because it has the smallest forward bias voltage resulting a very low power. The function of this LED is as a light source that will emit light to Photodioda. The LED used in this study has 3 mm diameter that can be seen below.

Fig. 3. LED [14]

4) Rotary Disk

Rotary disk is a special disk made of thin clear acrylic with a thickness of 3 mm and diameter of 12 cm. This disk will be placed between LED and Photodiode. The installation of Rotary Disk, Photodiode and LED can be seen in below.

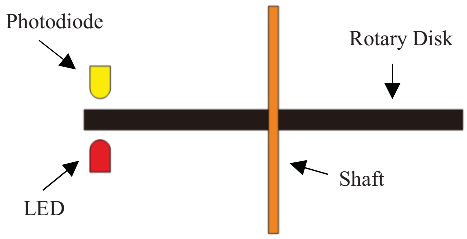

Fig. 4. Installation of Rotary Disk, Photodiode and LED

The function of this disk is to reduce the intensity of the light from the LED into Photodiode. Reduction of light intensity must be directly proportional to the angle function. In order for the disk to have such that function, the rotary disk must have a color gradient from black to clear from an angle of 0° to 360° angle.

The shape and color of this rotary disk can be seen below.

Fig. 5. Rotary Disk

It can be seen in Figure 5 that each angle has a different color. The LED light will decrease its intensity to 0% when it comes in the black area. Under this condition, Photodiode will receive very little light because the LED light is obstructed by the black color. The analog voltage generated by Photodiode will be of little value. When the LED is in the clear area (in Figure 5 is white) then the intensity of light will rise to 100% since all LED light will be emitted to Photodiode. Photodiode will receive all the light from the LED so that the resulting analog voltage will be of great value. When the LED position is between black and clear or in the gray color, the led light will decrease according to the gray color level on the rotary disk. This will cause the analog voltage generated by the Photodiode will vary when the rotary disk is rotated. This analog voltage will be read by microcontroller and will be converted to an angle value.

5) Stainless Steel Arrow

The stainless steel arrow is an arrow that functions as a wind direction indicator. This arrow is made of stainless steel and has several parts namely the tip of the arrow, tail, and stainless shaft. The shape and parts of this stainless steel arrow can be seen below.

Fig. 6. Shape and Parts of Stainless Steel Arrow

The arrow tip serves as a sign of the wind direction that occurs, while the tail use to direct the stainless steel arrow. Because the tail functions to direct the arrow, then the tail should be made with a large plate sheet with the size of 15 cm x 21 cm. This will lead to a large area of the wind catch. The large area of the wind catch makes the arrows become easier to move because of a little wind. This will make this wind direction sensor more sensitive. Shaft use as a pedestal of the arrow in motion, as well as a shaft for the moving rotary disk.

The five hardware components will be assembled into a wind direction sensor according to the block diagram shown below.

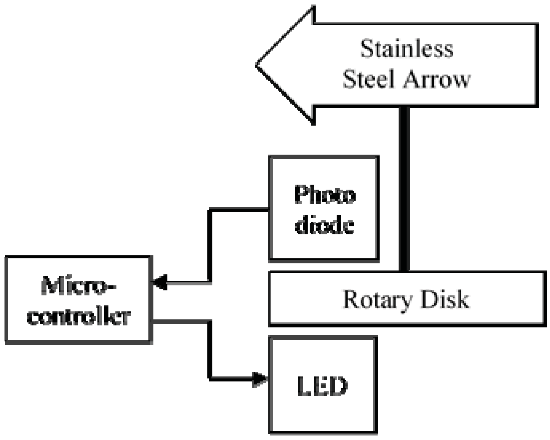

Fig. 7. Block Diagram

In this block diagram, the LED emits a light that will approach the Photodiode. But this LED light will go through the rotary disk first before approaching the Photodiode. This rotary disk has a gradation color from black to clear in each angle. This causes the LED light approaching the Photodiode has different intensity in each angle. This results in different photodiode resistances. By using a resistor, the resistance values can be converted to analog voltage. The analog voltage generated by Photodiode will enter into Analog Digital Converter (ADC) on microcontroller. This analog voltage value will be converted to an angle value inside the microcontroller. Then this angle value will be sent to the PC via serial communication. PC only use to display the output of the sensor. PC is not part of the wind direction sensor because it is only for display the output of the sensor. The sensor itself already has the angle value of wind direction. The five components above were arranged according to the block diagram shown in Figure 7. The wind direction sensor created is shown below.

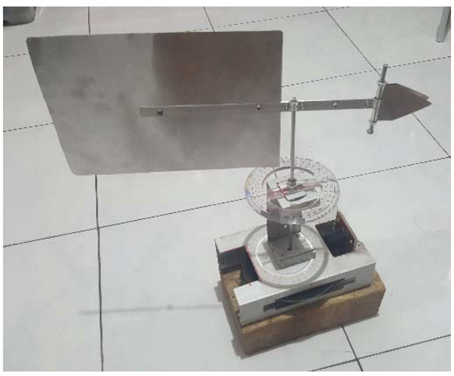

Fig. 8. Wind Direction Sensor

B. Software

As mentioned before, in this study the wind direction sensor converted the voltage value of the photodiode analog into the angle value. Therefore a program was needed to do that. This program would be placed in the microcontroller. This program was created using C language. The program was made according to the flowchart shown below.

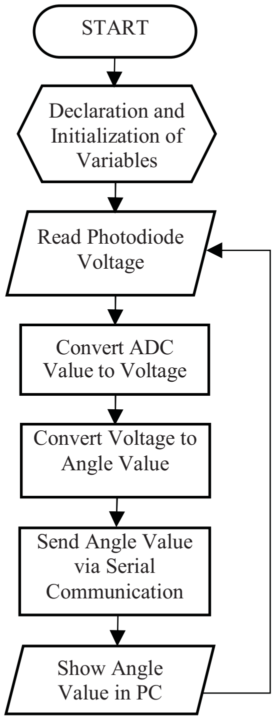

Fig. 9. Flowchart Sensor

The program starts with the process of declaration and initialization of variables used. After that, the program will read the ADC value of the Photodiode voltage that comes into the microcontroller. This ADC value has a range from 0 to 1023, due to microcontroller ADC has values up to 10 bits. Then this ADC value will be converted into voltage value by using equation (1) [15].

$$v = \frac{a \, x \, 5}{1023} \tag{1}$$

Where:

v = photodiode voltage (V)

a = ADC value

After that the voltage value is obtained it will be converted into the angle value by using the equation. The equations that relate the voltage value and the angle value will be searched by a test by using regression analysis technique.

C. Test

In this study two tests were conducted. First, the test to determine the conversion equation that would be used as the sensor reference to change the value of Photodiode voltage to wind direction angle value. Second, the test to determine the percentage value of wind angle error that produced by this device. Both of these tests were conducted at the Electric Circuit Laboratory at Institute of Technology of Sepuluh Nopember in Surabaya, Indonesia. The conversion equation was searched by comparing Photodiode voltage value with the angle value that measured using a protractor.

The protractor would be placed under the stainless steel arrow as shown below.

Fig. 10. Placement of the Protractor

Photodiode voltage data were taken for every 15° angle. Photodiode voltage data for every 15° angle would produce 24 sampling data. These data would be the regression analysis data. The equation used to produce a polynomial equation that illustrating the relationship between the voltage generated by Photodiode and the angle value is shown in (2) [16].

$$\begin{bmatrix} n & \sum_{i=0}^{n} x_i & \sum_{i=0}^{n} x_i^2 & \cdots & \sum_{i=0}^{n} x_i^m \\ \sum_{i=0}^{n} x_i & \sum_{i=0}^{n} x_i^2 & \sum_{i=0}^{n} x_i^3 & \cdots & \sum_{i=0}^{n} x_i^{(m+1)} \\ \sum_{i=0}^{n} x_i^2 & \sum_{i=0}^{n} x_i^3 & \sum_{i=0}^{n} x_i^4 & \cdots & \sum_{i=0}^{n} x_i^{(m+2)} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \sum_{i=0}^{n} x_i^m & \sum_{i=0}^{n} x_i^{(m+1)} & \sum_{i=0}^{n} x_i^{(m+2)} & \cdots & \sum_{i=0}^{n} x_i^{2m} \end{bmatrix} \begin{bmatrix} c_0 \\ c_1 \\ c_2 \\ \vdots \\ c_m \end{bmatrix} = \begin{bmatrix} \sum_{i=0}^{n} y_i \\ \sum_{i=0}^{n} x_i y_i \\ \sum_{i=0}^{n} x_i^2 y_i \\ \vdots \\ \sum_{i=0}^{n} x_i^m y_i \end{bmatrix} \quad (2)$$

Where:

n = degree of polynomial

x_i = independent variable x

y_i = dependent variable y

c_m = coefficient of polynomial

This equation will be put into the conversion equation shown in the flowchart in Figure 9. After the conversion equation was found, the second test was performed by taking 10 sampling data of the angle values beyond the 24 sampling data obtained from the first test. The angle value that read by the sensor were compared to the angle value of the protractor. This value is the error value generated by the wind direction sensor that made in this study. The smaller the error value, the better the wind direction value that generated from the sensor.

III. Result and Discussion

As previously explained that the production the wind direction sensor there were two tests performed. The first test was to find the relationship between photodiode sensor voltage and wind direction angle. The test was done by measuring the photodiode voltage value and the angle value that indicated by the protractor. Both values weare recorded in a table. This test was performed 24 times so as to produce data as much as 24 data that represented for every 15° angle. The data of the voltage and angle values can be seen in Table 1.

Table 1. Data of the 1st Test

No	deg.(°)	v_p (V)	No	deg.(°)	v_p (V)
1	0	0.0880	13	180	2.5904
2	15	0.0978	14	195	2.7468
3	30	0.2590	15	210	2.8201
4	45	0.3470	16	225	3.0499
5	60	0.4888	17	240	3.3773
6	75	0.5767	18	255	3.6266
7	90	0.7771	19	270	3.7928
8	105	0.9042	20	285	3.8319
9	120	1.1046	21	300	3.9980
10	135	1.4027	22	315	4.0811
11	150	1.8719	23	330	4.3109
12	165	2.1065	24	345	4.3939

After obtaining the data, then a graph was made on the Cartesian axis. The data in Table 1. were transferred in a plot with X-axis as the Photodiode sensor voltage and Y-axis as the angle value that indicated by the protractor. The plot would generate 24 coordinates on the graph. From these 24 points, a graph was made by performing the polynomial regression analysis at 3rd degree. The graph result from the calculation of polynomial regression analysis can be seen below.

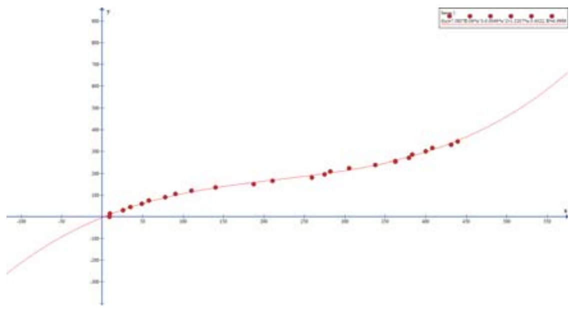

Fig. 11. Graph of the Relationship Between Photodiode Voltage and the Angle of Wind Direction

From the graph shown in Figure 11, the relationship between Photodiode voltage and the wind direction angle was formulated by equation (3).

$$d = 7.38x10^{-6}v^3 - 0.0049v^2 + 1.52v - 3.4322 \quad (3)$$

Where:

d = wind direction (°)

v = photodiode voltage ($x10^2$V)

This equation was a conversion equation that would be put into the program on microcontroller. As shown in Table 1. The photodiode voltage never reaches zero value. After that, a test was performed to determine the error value that generated by the wind direction sensor. The sensor will be rotated in a certain direction with an angle value beyond the angle recorded in the first test. This test was performed 10 times by performing the angular readings that indicated by the protractor and the wind direction sensor which were recorded in a table.

The experimental data are shown in Table 2 below.

Table 2. Data of the 2nd Test

No	deg.$_{protractor}$ (º)	deg.$_{sensor}$ (º)	Error (%)
1	180	182.44	1.36
2	200	204.92	2.46
3	220	218.86	0.52
4	240	241.08	0.45
5	260	259.18	0.32
6	280	280.81	0.29
7	300	299.18	0.27
8	320	320.05	0.02
9	340	341.03	0.30
10	350	349.15	0.24
Average			0.62

From Table 2, it can be seen that the measurement error generated by the wind direction sensor has been made was 0.62%.

During this study, the production of wind direction sensor required several components. There are 2 types of component. They are sensor part and mechanical part. The list of mechanical part and sensor part and their prices can be seen in Table 3 below.

Table 3. Components Price List

No	Component	Cost (Rp)
Mechanical Component		
1	Stainless Steel Shaft Diameter = 4 mm Long = 25 cm	3.000
2	Stainless Steel Plate 25 cm x 25 cm Thickness = 0.4 mm	3.800
3	4 Bearing Diameter = 4 mm	28.000
Total Cost of Mechanical Part		**34.800**
Sensor Component		
4	2 Circle Acrylic Transparant Thickness = 1.5 mm, Diameter = 12 cm	9.000
5	2 Resistors	100
6	LED Diameter = 3 mm	200
7	Photodiode Diameter = 3 mm	200
8	Transparency Sticker Printing	3.000
9	Acrylic Black 10 cm x 5 cm Thickness = 3 mm	3.000
Total Cost of Sensor Part		**15.500**
Total Cost		**50.300**

From Table 3, it can be seen that the cost of mechanical component is Rp. 34.800 and the cost of sensor part is Rp. 15.500, and the total production cost of the wind direction sensor with light intensity method was only 50.300 rupiah or only about 3.5 US Dollar (1 USD = Rp. 14.434,60).

IV. CONCLUSION

This study produced a new wind direction sensor using the light intensity method. This method only utilized LED and Photodiode sensor in determining wind direction. From the tests that have been conducted, it can be seen that this sensor had a measurement error of 0.62%. In addition, this sensor had a low production cost. The production cost of the wind direction sensor was only 50.300 rupiah or only about 3.5 US Dollar. From the value it can be concluded that the wind direction sensor made in this study was very well used to measure wind direction that occured in a certain place and it could be produced with very cheap cost.

ACKNOWLEDGMENT

First, the author would like to express gratitude to Allah SWT because of His permission, the author could finish the study entitled Design A Low Cost Wind Direction Sensor with High Accuracy. The author is also thankful to the Ministry of Research, Technology and Higher Education of the Republic of Indonesia which has provided funds for this study. The author also gratefully acknowledge the Institute of Technology of Sepuluh Nopember which has provided facilities and infrastructure to support the implementation of this study. The greatest appreciation also goes to University of Widya Kartika and my parents, Mr. Ali Fikri and Mrs. Pancawati, who never stop support the completion of this research

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