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AN INEXPENSIVE ANEMOMETER USING ARDUINO BOARD *

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Abstract. *In all studies involving wind speed, such as meteorology, wind turbines and agriculture accurate speed information for decision making is required. There are several types of anemometers, with medium and high costs, such as cup, hot wire and pitot tubes, the hot wire being more sensitive and expensive than others. The device developed in this work is the cup anemometer, that is easy to build. The great advantage of this device is the low cost, with an approximate value of US$ 50.00, using simple materials that are easy to find in commercial stores. The Reed Switch sensor is also another advantage as it does not require a sophisticated programming, as well as the open platform Arduino. The use of theoretical aerodynamic drag coefficients and the presented calculations resulted in values very close to a commercial anemometer. The coefficient of determination between the cup Anemometer and the standard sensor of Meteorological Research Institute IPMet/Brazil is R^2=0.9999, indicating strong correlation between the instruments. As the reference anemometer (IPMet) has high embedded technology and the prototype is low cost, we conclude that the project has an attractive cost benefit for possible development and production, reaching the objective of this work.*

Key words: *Anemometer, low cost, airspeed measurement, Arduino, open hardware*.

1. INTRODUCTION

This work is an extended version presented in [1], where the operating principles of a low-cost anemometer were presented. This anemometer is a part of the Electronic Meteorological Station Project [2], authorized by the Campus Director and developed by ENACO-Energy and Related Applications [3], Catanduva-SP-Brazil. The Meteorological Station will promote the development of other surveys and will also assist the city civil defense and micro-region farmers in alerting the population, making decisions, keeping historical data.

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There is a wide variety of anemometers, the most common being Cup anemometers. They consist of cups attached to stems that are fixed to a central axis. Other anemometers, such as a hot wire that measures temperature change of wire heated electrically by the passage of wind; pitot probes use the Bernoulli Principle and the propeller anemometers have a front propeller to determine wind speed.

The first anemometer applying scientific principles was developed by [4]. In the work developed by [5], the authors present historical fragments on the technological evolution of the anemometers and in the study of [6], the various types of anemometers and their applications are presented.

In the research developed by [7], the authors present the importance of knowledge of basic meteorological data to assess the impacts of climate variability, predicting impacts on hydrology and agroecosystems using a high-resolution network, showing that the meteorological data set increases significantly the availability of climatic data in Brazil.

The authors [8] present a bibliographical review of researches involving wind speed and prediction for wind energy, being a source of bibliographic consultation.

The researchers [9] proposed a low-cost ultrasonic planar anemometer with a very interesting price-performance ratio that was obtained with the use of Arduino architecture, producing a simple, original and innovative system.

In the solar collector surveys developed by [10], [11], [12] and [13], the authors used the same type of anemometer with identical results to those presented in this work. As evacuated solar collectors were used, the wind speed had insignificant influence on the results. This kind of solar collector isolates the outside air by both glass and vacuum. Therefore, the results were not used in the thermal efficiency calculations.

In the meteorology studies, the anemometer is an important instrument in the atmospheric analyses [14] and [15], where the authors used the equations of angular motion and frequency to determine the rotation of the instrument. In the work developed by [16], the authors discuss a study involving ultrasound transducers to measure wind speed at an approximate cost of US$ 150.00. The researchers [17] studied the influence of lattice towers on the cup anemometers, analyzing the best distance of less turbulence between the tower and the anemometer. To develop a rotational anemometer of conical cups, [18] used in electronic blocks system, requires calibration to validate the results. Another application of the anemometer is in the estimation and measurement of the efficiency of wind turbines [19]. The most common use of cup anemometers is in meteorology and agriculture, to optimize agricultural practices with more precise decision-making. The use of this equipment in Brazilian agriculture is limited by its high cost [20]. Despite the calibration, the instrument developed by [20] does not provide readings for speeds below 0.85 m/s. In the study developed by [21], 3 types of anemometers were tested in food greenhouses, showing that this instrument is very important to help in the technological development of agriculture. Instead of using the first-degree function in anemometer calibration, [22] uses two harmonic constants, which represent the influence of cup geometry. Also [23] refers to the use of anemometers in wind energy and uses the front and rear drag coefficients and the radius of rotation to determine the instrument constant.

The eolian sector depends exclusively on precise measurements of wind speed and an instrument, so it is necessary to have reliable instruments [24].

The device chosen for this work is the cup anemometer because it is simple and uses only a reed-switch sensor to measure the rotation of the device.

The objective of the work is to construct a low-cost cup anemometer with good efficiency. The device uses the electronic system in the Arduino platform with embedded software, because it is simple and easy to construct, besides being of low cost and easy access.

2. Materials and Methods

As the objective of the work is to construct a low-cost anemometer with good efficiency so that any low-income farmer can install this equipment in his property. With this proposal, we look for cheap materials and find in any store of screws and supermarkets.

The construction begins with the machining of an aluminum central shaft with fillister for coupling of a simple bearing. The other machined part is the central nylon bracket. Three 70 mm aluminum confectionery cups were used. The three cups were bolted to three 5mm diameter threaded rods with locking nuts and washers. The rods were coated with thermosetting plastic tubes for protection against the weather. The neodymium magnet is glued to the underside of the central nylon support, Fig. 1.

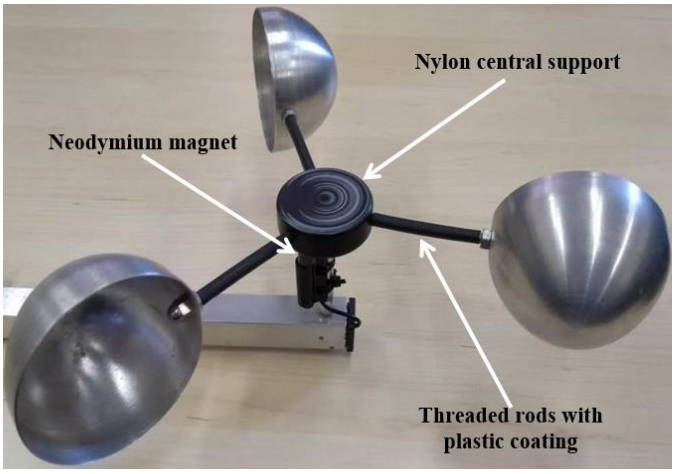

Fig. 1 Anemometer mounted with threaded rods with the plastic coating, neodymium magnet, and nylon central support

The top view of the anemometer with the stems, the central bearing, and the cups with its hemispherical form is shown in Figure 2. As the cup anemometer was calibrated beside the standard sensor, the friction is implicit in the calibration. The radius dimension "r = 0.11433 m" is the only factor dependent on the construction of the instrument, is measured using a pachymeter in millimeters and the result of the measurement was converted into meters. The cups depend exclusively on aerodynamic coefficients.

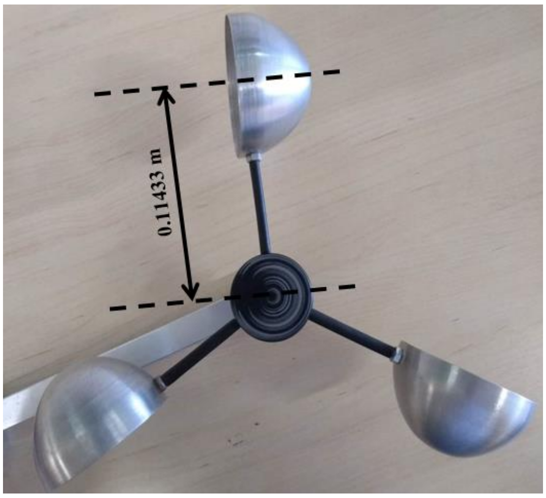

Fig. 2 Top view of anemometer with a radius of 0.11433 m

The reed-switch [25] is of the "normally open" type and for appropriate operation, the spacing between the magnet and the sensor must be at most 3 millimeters. The moment these two components intersect, the "S1" sensor closes the reed-switch circuit, counting one pulse at each revolution.

The advantage of this circuit is its simplicity of construction and assembly in addition to the low cost of production. The reed-switch, Arduino board, and neodymium magnet sensor values are US$ 0.99, US$ 3.50 and US$ 1.19, respectively. The circuit with the components is shown in Fig. 3. The Arduino was connected to the computer, being the main source of power of the circuit. The cup anemometer operating voltage is the input/output USB computer connected to the Arduino. The standard IPMet-UNESP anemometer has the same power supply, that is, connection by the USB input/output of the computer of that Institute of Meteorological Research.

The pulse register is counted and controlled by the Arduino software [26], which was previously loaded into the microcontroller memory.

The 10 kΩ resistor works as a pull-up, which ensures that the input of the logic system is set to the expected logical level of the external devices, i.e., the reed-switch.

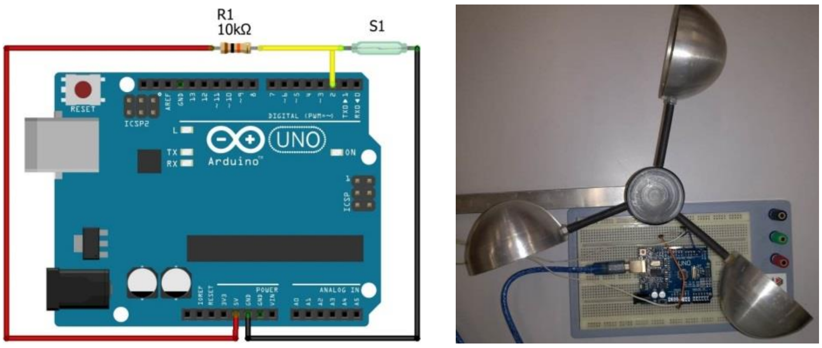

Fig. 3 Electronic circuit with reed-switch sensor connection to Arduino microcontroller

To calculate the airspeed, [27] suggest the calculation procedure described in Equations (1), (2) and (3), where k_d is a dimensionless relationship between the frontal and rear drag coefficients are $c_{d1} = 1.42$ drag $c_{d2} = 0.3$, respectively, from reference [28]. The anemometer dimensionless factor (K), also suggested by [27], is defined by the aerodynamic characteristics of the cups, extracted from Equation (1) or a relationship between airspeed (V) [m/s], anemometer radius r = 0.11433 m and angular speed (ω) defined in Equation (4) [rad/s].

By Equation (5) is determined airspeed in $[\mathrm{m/s}]$. The index (f) represents the pulses per each revolution measured at reed switch sensor.

$$k_d = \sqrt{\frac{c_{d1}}{c_{d2}}} \tag{1}$$

$$K = \frac{V}{r \cdot \omega} = \frac{k_d + 1}{k_d - 1} \tag{2}$$

$$V = K.\omega.r \tag{3}$$

$$\omega = 2.\pi.f \tag{4}$$

$$V = 2.27f \tag{5}$$

The complete Arduino programming can be found in the Appendices of [30].

Equation (3) is used to calculate the uncertainty of the sensor because it contains the radius, which is the variable of the anemometer. The term "f" refers to the number of pulses measured by the reed-switch sensor. This sensor does not fail and if this occurs, the cup anemometer does not work.

Deriving the Equation (3), it is found the partial derivatives that follow:

$$\frac{\partial V}{\partial r} = k.\omega \tag{6}$$

Equation (7) is used to calculate the mean uncertainty of the anemometer cup:

$$\bar{\delta} = \sqrt{\left(\frac{\partial V}{\partial r}\right)^2 \cdot \delta_r^2} \tag{7}$$

The mean anemometer uncertainty value is $2.12 \cdot 10^{-8}\ m/s$. The standard sensor accuracy is 1%.

2.1. Programming the Arduino platform

The Float variable "wind" of Arduino software is shown in Fig. 4.

```
//*********************************************
//Anemometer variable
const int wind_pin = 2;  //pin 2 - Anemometer
float wind;
//*********************************************
```

Fig. 4 Float variable "wind"

The wind speed is calculated from constant 2.27 in Arduino software, using Equation (5), as shown in Fig. 5. The acronym (f) represents each pulse measured by the reed-switch sensor in [Hz].

```
}
pulse = 1000.0*countPulse/(millis()-timeold);
if (pulse==0){
  AirSpeed=0;
}
  else if (pin==2){
    AirSpeed = 2.27 * f;
  }
     }
}
```

Fig. 5 Part of Arduino software.

The complete Arduino software can be found in the Appendices of [30] and the calibration equation is shown in Figure 6. The calibration procedure of the cup anemometer for instrument certification was carried at IPMet-UNESP Bauru/Brazil [31] from 08:00 am to 5:33, with a measurement interval of 1 minute. This means that the sample size (number of measurements) was 727. The reference instrument was a propeller anemometer [32], generating a linear function and coefficient of determination (R^2), which were included in the graphic of Fig. 6. With the anemometer airspeed V_{Cup} is inserted into calibration equation, thus obtaining the calibrated airspeed (V_{Real}) and the calibration equation is shown in Equation (8).

$$V_{Real}[m/s] = 0.9864 \cdot V_{Cup}[m/s] - 0.0021 \tag{8}$$

Equation (8) was used only to obtain a comparative check between the anemometer cup and the IPMet standard sensor, i.e., Equations (1), (2), (3), (4) and (5) are sufficient for wind speed calculation, as defined by [23]. In Equation (8), the value 0.0021 represents the point at which the trend line generated from the point cloud intercepts the ordered axis, as shown in Figure 6.

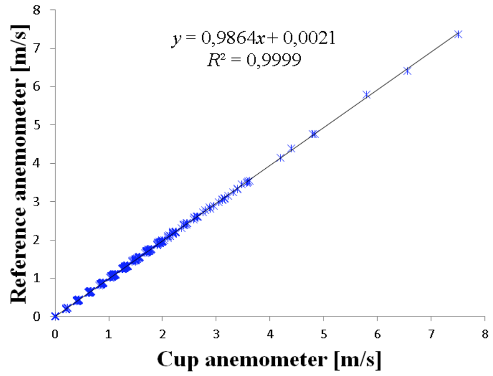

Fig. 6 A calibration curve using cup anemometer and reference sensor of IPMet-UNESP Bauru

A positive linear correlation between cup anemometer speeds and the reference anemometer is shown in Fig. 6. The variables increase and decrease proportionally, indicating a strong linear relationship. This calibration curve, using the most widely accepted criteria, should be performed from 0 to 8 m/s since the predominance of winds at the standard sensor site is 0 to 8 m/s on normal days. For higher speeds analysis, it would only be possible on stormy days.

It is also observed in Fig. 6 that the coefficient of determination (R^2) was 0.9999. This means that 99.99% of the total variation of the anemometer speed is explained by the regression line, confirming that the calibration of the cup anemometer compared to standard IPMet was successful.

A comparison between the speeds obtained with the standard IPMet sensor and the cup anemometer is shown in Fig. 7. We verified that 91% of the measurements of the anemometer cup are above of the standard anemometer and 9% below. The differences are best seen in Fig. 8.

Continuing the analysis of Fig. 7 and Fig. 8, it is possible to see that the instruments work with very similar results.

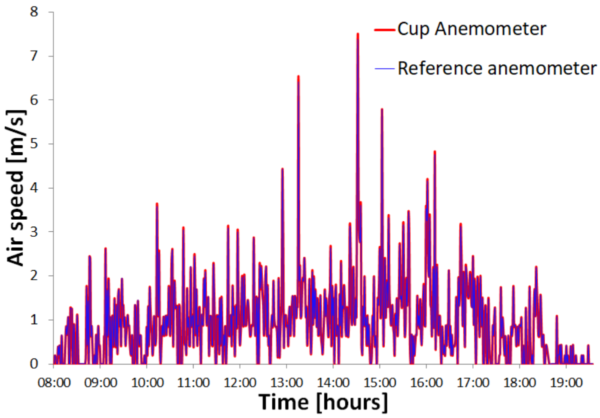

Fig. 7 Airspeed comparison curves between the cup anemometer and the reference sensor of the IPMet-UNESP Bauru

The percentage difference between the cup anemometer and the IPMet-UNESP standard anemometer is shown in Fig. 8. The positive values represent the differences found above the prototype with respect to the standard, while the negative values represent the difference below the standard.

We can also observe that the maximum and minimum amplitudes of the differences from the standard are 2.29% above and 1.05% below, respectively. These differences can be explained by the theoretical use of the values of the drag coefficients, which were extracted from [28]. More precise values of the drag coefficients could be obtained with an experimental wind tunnel analysis. Another justification is the possibility that the radius of 0.11433 m has a small variation in one of the shells in relation to the center of rotation of the cup anemometer. This can change the linear velocity (see equation 3) depending on the direction of the wind.

As the reference anemometer (IPMet) has high embedded technology and the prototype is low cost, we conclude that the project has an attractive cost benefit for possible development and production, reaching the objective of this work.

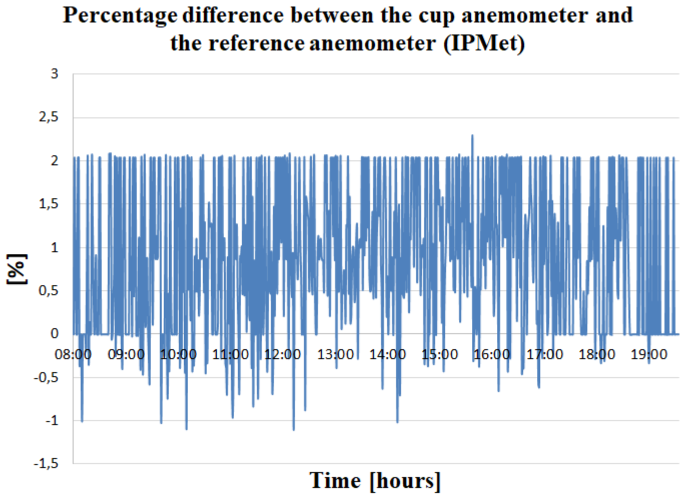

Fig. 8 Percentage difference between the cup anemometer and the reference anemometer (IPMet)

3. CONCLUSION

The cup anemometer showed excellent agreement with the reference sensor. It is a great choice not only for small farmers, but also for evaluation of wind turbines and especially for meteorological stations.

The great attraction of this instrument is its low cost, with an approximate value of US$ 50.00, considering the time of machining. Constructive simplicity is another interesting factor in this instrument.

As the reference anemometer (IPMet) has high embedded technology and the prototype is low cost, we conclude that the project has an attractive cost benefit for possible development and production, reaching the objective of this work.

Future activities should be also focused on the development of more accurate machining and assembly processes of the cup anemometer, and the use of real drag coefficients getting directly from a wind tunnel test. These procedures could further increase the precision of the sensor.

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