Digital Wind Speed and Angle Measuring System

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ABSTRACT

The measurement of wind speed and direction are the most important factors in weather prediction. They can be measured by a variety of tools. The most common, complete portable system is the anemometer, which typically consists of a rotating vane to measure the direction and a shaft with cups that rotate with the wind to measure its speed. There are various models presented for the dynamic of the three cup anemometer and the area dynamic drag coefficient model has been employed in this project. The area dynamic drag coefficient model has been developed to calculate the ratio of the regressive and progressive area dynamic-drag coefficient of the anemometer cups using the half covered anemometer model. So the anemometer factor can be obtained experimentally without using any other standard anemometers and it can be easily calibrated. The half covered cup system was found to be more sensitive than the open cup system and also it was found that the length of the cup arm should be twice the cup diameter for optimal performance. Various vane types have been studied and "an aerofoil" type of cross-section was found to be superior to other types.

1. INTRODUCTION

1.1 The Wind Vector

The wind is a vector quantity which can be measured and processed quantitatively. It is common to measure and to process the scalar components of the wind vector, the wind speed (the magnitude of the wind vector) and the wind direction (the orientation of the wind vector) separately.

1.2 The Wind Speed Measurements

The wind speed is measured using 'Anemometers'. There are various types of anemometers. Some are highly responsive and can be used to define the detailed turbulent structure of the wind; whilst others are better suited to measure the mean wind speed. The mean speed at a particular height above ground is important for many applications such as wind resource assessment, power performance testing and characterization of acoustic emission and it is measured using the three-cup anemometer. A cup anemometer conventionally consists of three hemispherical or conical cups, arranged in a horizontal rotor configuration around a central vertical shaft that drives a signal generation device.

Mechanical and digital anemometers are currently being used to measure the wind speed. The inability to measure short variations and necessity to perform mathematical calculations to obtain the wind speed can be highlighted as the main drawbacks of the mechanical system. Though the available digital anemometers are of high accuracy and require no calibration; their usage is limited by their high cost.

The designed system has much more advantages comparing to the above. It can be calibrated easily without the help of another anemometer. Readings can be obtained instantly without involving any mathematical calculations. It is a low cost system and can be handled easily and the direction of the wind can also be measured at the same time.

The force on the concave side of any cup, due to the wind, is greater than that on a convex side in a similar position, because the area drag coefficients of each side is not equal, so the cup wheel rotates. The rate of rotation does not depend on the direction of the wind, nor to an appreciable extent on the density of the air.

Before using the anemometer for practical applications it must be calibrated. To conclude the most suitable cup anemometer the following quantities are important to determine experimentally.

Relationship between the wind speed and the cup rotary speed → Static torque on the cup system at rest → Dynamic torque

Figure 1: The basic steps of an anemometer calibration

Various diameters and shapes of the cups and various lengths and diameters of the supporting arms should be considered experimentally in order to determine the best possible setup. Theoretical predictions of the best dimensions are impossible. To measure the wind speed, cup wheel is connected to a mechanical counting system which records the number of revolutions of the cup wheel.

2. METHODOLOGY

2.1 The Open Cup Anemometer

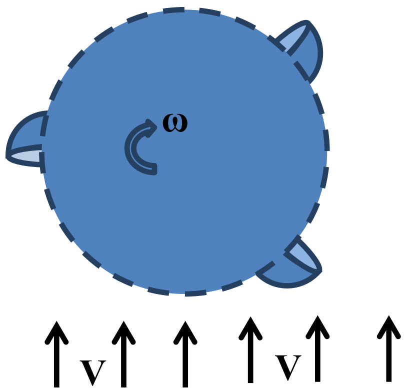


Figure 2: The open cup anemometer

Figure 2 shows an open cup anemometer with three cups. The cup anemometer is mounted with its axis vertically.

Let **V** be the horizontal component of wind velocity, **ω** the cup wheel angular velocity, **R** the cup-arm length (length between center of the wheel and center of the cup), **d** the cup diameter, ρ the density of air and C_{D1} & C_{D2} the aerodynamic drag coefficients of the cup in regressive and progressive phases respectively.

Let's consider the relative motion of the cup with respect to the wind velocity.

In the left half of the figure 2, the velocity of the anemometer cup and the velocity of the wind, both are in the same direction. Hence the torque produced by the left half is,

$$C_{D1}(V - R\omega)^2 . \frac{\rho}{2} . \frac{\pi d^2}{4} R \qquad (1)$$

In the right half of the figure 2, the velocity of the anemometer cup and the velocity of the wind are in opposite direction. Hence the torque produced by the right half is,

$$C_{D2}(V + R\omega)^2 . \frac{\rho}{2} . \frac{\pi d^2}{4} R \qquad (2)$$

In a steady state the accelarating torque balances the frictional torque of the shaft [1].

$$C_{D1}(V - R\omega)^2 \frac{\rho}{2} . \frac{\pi d^2}{4} R - C_{D2}(V + R\omega)^2 \frac{\rho}{2} . \frac{\pi d^2}{4} R = frictional\ torque \qquad (3)$$

Normally the frictional torque is very small compared with the aerodynamic torque and can be omitted [2].

$$C_{D1}(V - R\omega)^2 \frac{\rho}{2} . \frac{\pi d^2}{4} R - C_{D2}(V + R\omega)^2 \frac{\rho}{2} . \frac{\pi d^2}{4} R = 0 \qquad (4)$$

$$\frac{C_{D2}}{C_{D1}} = \left(\frac{1 - \frac{R\omega}{V}}{1 + \frac{R\omega}{V}} \right)^2$$

$$f_o = \frac{R\omega}{V} = \frac{1 - C}{1 + C} \qquad (5)$$

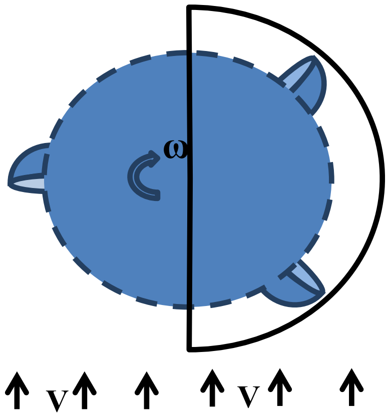
Where f_o is the anemometer factor and C is the square root of the ratio between regressive and progressive aerodynamic drag coefficients

$$C = \sqrt{\frac{C_{D2}}{C_{D1}}} \qquad (6) \qquad\qquad V = \frac{R\omega}{f_o} \qquad (7)$$

The ratio $\frac{R}{f_o}$ is a constant for the given anemometer. The angular velocity of the cup can be detected using the sensor. So the value of the wind speed can be calculated using equation (7). In order to find the value of C, the half covered cup system had to be considered.

2.2 The Regressive Half Covered Cup Anemometer

Consider the regressive half covered system anemometer shown in figure 3. Velocity of the covered region is zero (V=0). At steady state the net accelerating torque must equal to the shaft frictional torque. It is possible to obtain the following expression by assuming that the frictional torque is negligible.



$$C_{D1}(V-R\omega)^2\frac{\rho}{2}.\frac{\pi d^2}{4}R - C_{D2}(R\omega)^2\frac{\rho}{2}.\frac{\pi d^2}{4}R = 0$$

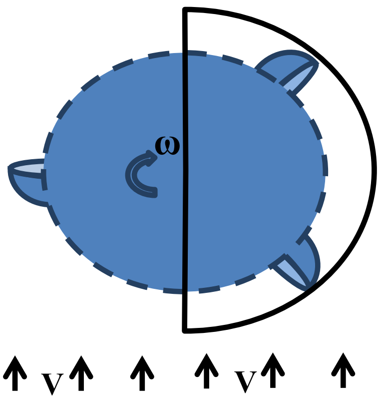
$$\frac{C_{D2}}{C_{D1}} = \left(\frac{1-\frac{R\omega}{V}}{\frac{R\omega}{V}}\right)^2$$

$$f_1 = \frac{R_1\omega_1}{V_1} = \frac{1}{1+C} \qquad (8)$$

Figure 3: The regressive half covered cup anemometer

2.3 The Progressive Half Covered Cup Anemometer

Consider the progressive half covered system anemometer as shown in figure 4. Velocity of the covered region is zero (V=0).



$$C_{D1}(R\omega)^2\frac{\rho}{2}.\frac{\pi d^2}{4}R - C_{D2}(V-R\omega)^2\frac{\rho}{2}.\frac{\pi d^2}{4}R = 0$$

$$\frac{C_{D2}}{C_{D1}} = \left(\frac{\frac{R\omega}{V}}{1-\frac{R\omega}{V}}\right)^2$$

$$f_2 = \frac{R_2\omega_2}{V_2} = \frac{C}{1+C} \qquad (9)$$

Figure 4: The progressive half covered cup anemometer

The angular frequency of regressive half covered cup system is given by

$$\omega_1 = \frac{1}{R_1(1+C)} . V_1 \quad (10)$$

The angular frequency of progressive half covered cup system is given by,

$$\omega_2 = \frac{C}{R_2(1+C)} . V_2 \quad (11)$$

When $R_1=R_2$ and $V_1=V_2=V$

$$\omega_1 = \frac{1}{C} . \omega_2 \quad (12)$$

The gradient of the graph of ω_2 $Vs. \omega_1$ is $m_1 = 1/C$

The ratio of C_{D1}: C_{D2} and C can be calculated using equation (12). If the ratio of the cup arm length and the anemometer factors are known, the wind speed can be calculated for a given angular velocity of the cup wheel. It is easy to determine the angular velocity of the cup wheel using the infrared sensor and the electronic circuit.

2.4 Angle Measuring System

The magnetic north should be determined first with the aid of a compass and the angle 0 of the system should be defined to lie along the magnetic north and the wind direction is measured clockwise with respect to the magnetic north.

2.5 Overview of the System

The block diagram of the embedded system programing is shown in figure 5, which is controlled by a PIC16F877A re-programmable microcontroller chip [3] that is capable with enough memory and having enough number of I/O ports for the requirements.Timer-0 register module in the microcontroller can be used to count the digital output of the photo sensor, generating an interrupt when a desired number of events are occurred. The encoder is used to find the rotational direction. The stored data passed to LCD Module (LMB162) [4] is consisted with two lines to display data.

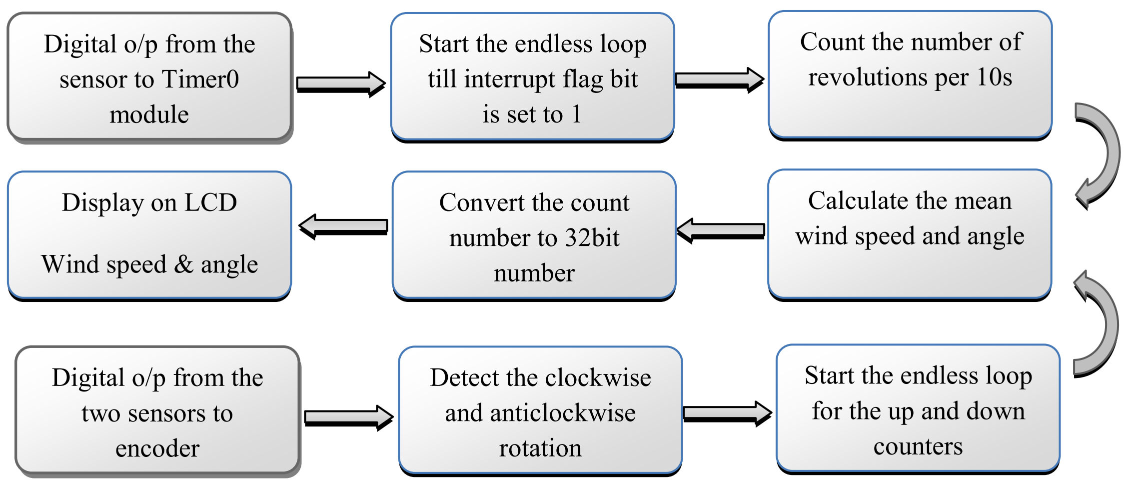


Figure 5: The block diagram of the embedded system

2.6 The Anemometer Calibration

All the cup anemometers are used for wind assessments to specify their current features; mainly the ratio of the area dynamic drag coefficients and frictional torque. According to the anemometer dynamics the anemometer sensitivity depends on the arm length of the cup wheel. Theoretically there is no limitation for the arm length. Hence most suitable arm length should be determined experimentally. To calculate the wind speed for a given angular velocity of the cup wheel, the anemometer factor of the anemometer should be determined experimentally and then it can be calibrated. Weekly recalibration is recommended in order to obtain accurate readings.

The wind tunnel is set to produce an un-turbulent steady horizontal flow. Typically the un-turbulence range of the wind tunnel is 0~5 ms^{-1}.The microcontroller was programmed to count the number of sensor output triggers per ten seconds and the collected data was transferred to LCD module.

3. RESULTS AND DISSCUSSION

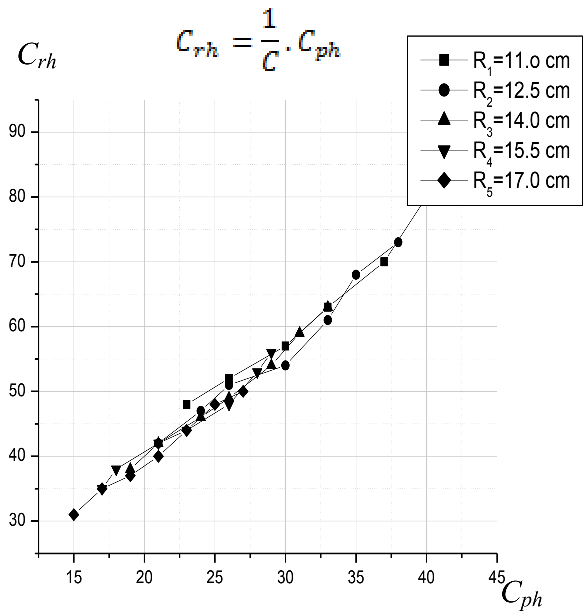


Figure 6: The variation of C_{rh} vs. C_{ph} for different value of arm lengths

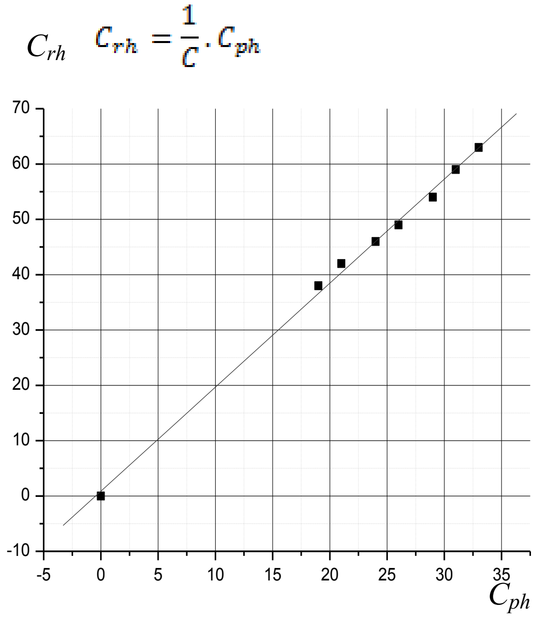


Figure 7: The variation of C_{rh} vs. C_{ph} for $R_3=14\times10^{-3}$m

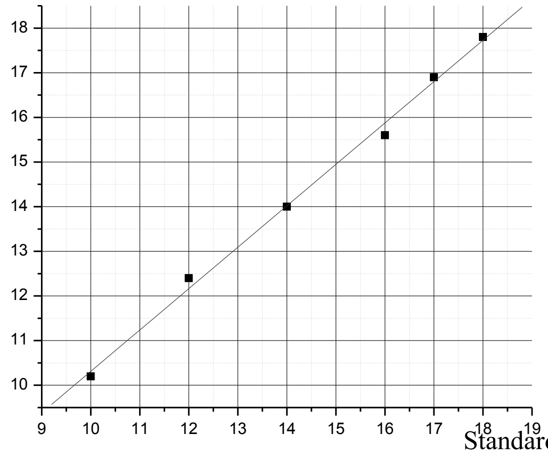
According to the figure 6, it was observed that the most linear variation of C_{rh} vs. C_{ph} is given by when $R = 14 \times 10^{-3}$ m, where the length of the cup arm was twice the cup diameter. Therefore the gradient of the graph (m) of C_{rh} vs. C_{ph} for $R = 14 \times 10^{-3}$ m [figure 7] was used to calculate C ($C = 1/m = 0.532 \pm 0.016$) and thereby corresponding anemometer factors for each system was calculated. The results are shown in table 1. For the standard anemometers, the anemometer factor varies between 2.5 and 3.5.

Table 1: The calibration table

Anemometer type	**Open**	**Regressive half covered**	**Progressive half covered**
Anemometer factor equation	$f_0 = \frac{1-C}{1+C}$	$f_1 = \frac{1}{1+C}$	$f_2 = \frac{C}{1+C}$
Calculated anemometer factor	0.306 ± 0.014	0.653 ± 0.007	0.347 ± 0.015

3.1 The Comparison with the Standard Anemometer

Calibrated value (km/h)



Standard value (km/h)

Figure 8: The variation of the Calibrated value vs. Standard value

3.2 The Wind Angle Measurements

The wind direction is reported as the direction from which the wind blows, not the direction towards which the wind moves. A north wind blows from the north, toward the south [5].

A weather vane or the wind vane is a device used to monitor the direction of the wind. It is usually a body mounted unsymmetrical and makes it free to rotate on a vertical axis; so that the direction of the resultant force operating on it is due to the pressure of the wind passing through the vertical axis. A photo sensor is used to count the angle with respect to previous angle and another two photo sensors to determine whether the rotation is clockwise or anticlockwise. The photo sensors are controlled by a PIC 16F877A microcontroller and the data is passed to LCD module to indicate the direction from which the wind is blowing with respect to the north and in a clockwise direction.

3.2.1 Wind Wanes
Vanes have been constructed of numerous shapes and sizes; several are indicated in figure 9. (a) consists simply of a flat plate; the splayed vane type (b) has a somewhat better response to varying wind direction; (c) has an aerofoil type of cross-section and is superior to (a) and (b) in its speed of response and stability; (d) is of an unconventional pattern but has a very quick response to variation in wind direction.

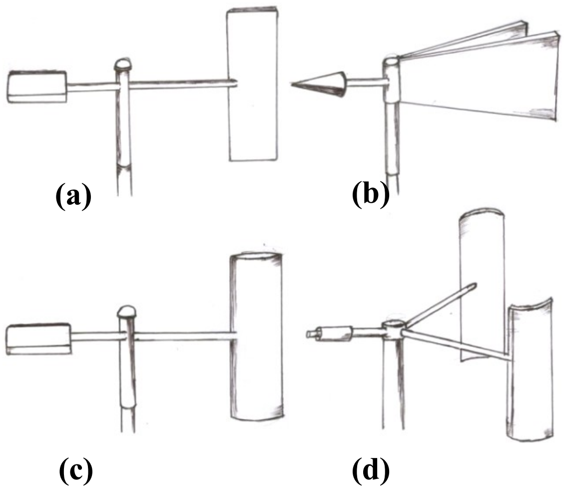


Figure 9: The different types of vanes

4. CONCLUSIONS

The most suitable arm length was found to be equal to the twice the cup diameter. The regressive covered cup anemometer was found to be more sensitive than open cup anemometer. The best performances can be achieved by using the same light material for both cups and the arms. The speed of response and stability of the vane varies with its shape and size.

REFERENCES

[1] Hunter, R.S., Wind speed measurement and use of cup Anemometry. *Recommended practices for wind turbine testing*, (2003) 60
[2] Sanuki, M.S.K., *The Performance of Half Covered Cup Anemometers* (University of Tokyo), (1963) 6
[3] Microochip, *PIC 16F877A datasheet*, (2003) 243
[4] Shenzhen TOPWAY Technology Co., Ltd. (n.d.). LMB162ABC LCD Module User Manual. *LMB162ABC LCD Module User Manual*, 11
[5] *Intermediate Energy Infobook*, National Energy Education Development Project, www.NEED.org, (2012) 26