# Computational Methods of Average Wind Speed and Direction

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***Abstract*** – **Wind speed and wind direction are usually taken using two parameters: wind speed and wind direction. This paper studies the average wind speed and direction calculation methods. The paper first introduces to basic wind's knowledge, and then presents several methods in calculating average wind speed and direction. Lastly some graphs are plotted base on these computational methods and the implementation of these methods in an actual buoy system.**

***Index Terms***— **wind speed, wind direction, mean, vector average.**

## I. INTRODUCTION

Wind is moving air which caused by differences in air pressure within earth atmosphere, from areas of high pressure to low pressure.

There are three major types of winds: upper winds, surface winds, and local winds. Upper winds can be found at least 10km above the ground, such as jet streams. Surface winds refer to the winds which are blowing near to the earth's surface. Usually it can be found at several km above the ground, such as trade winds. Trade winds often used by sailing ships during $18^{th}$ century as guides for crossing the Atlantic Ocean. Third one is local winds, which are occurring in a narrow region, such as land and sea breezes, which are found along the coastal areas.

Wind speed information is important in many areas, such as weather forecasting, aircraft and maritime operation, building and civil engineering. Strong wind will cause unwanted side effects and often bring negative effect to human. In weather forecasting, there are some famous wind disaster such as Hurricane Katrina, Hurricane Cyclone and Typhoon that always cause a huge demolition to victim country. An accurate method to obtain wind data and wind analysis work is essential to accurately predict when the wind disaster will come. Hence, preparation to avoid the disaster can be ready better. Besides, the wind is tightly related with the characteristic of the ocean wave. Wind waves are generated when wind blows across the water surface and momentum is transferred from the wind to the water. The wide range of research about ocean wave that generated by wind being performing in many countries.

Wind speed and direction can be measured with a variety of tools. The most common is anemometer, which typically consists of a rotational vane to measure direction and a shaft with cups attached that spins with the wind to measure its speed. Normally wind observations are taken at a fixed location using two parameters: wind speed and wind direction. Referenced to true north, wind direction is typically reported in degrees, and describes the direction from which the wind emanates. A direction of 0 degrees is due to North on a compass, and 180 degrees is due to South. A direction of 270 degrees would indicate a wind blowing in from the west. Wind speed is typically reported in miles per hour (mph) or meter per second (m/s). Reports for maritime and aeronautical operations may use knots (nautical miles per hour).

Wind speed is scalar quantity of wind velocity, which is magnitude of vector motion. Most of users of wind data require the averaged wind speed, usually expressed in polar coordinates as speed and direction. More and more applications also require information on the variability or gustiness of the wind. Hence standard deviations of wind speed and direction is computed.

Several average computational methods are introduced. Generally average value brings the meaning of arithmetic mean of a group of data. Average wind value can be calculated by using this method, but it does have some problems and limitations. Some other methods are introduced to solve the problem. The details will be discussed in part II in this paper.

## II. COMPUTATIONAL METHOD

### *A. Arithmetic Mean Method*

In mathematics, arithmetic mean is a method that sums the entire item in a list and divides the result by the total number of the items in the list. This method is commonly used in various applications, not only in meteorological data processing. By adding all the sampled data in a specific interval and divide with the total number of sample, average wind speed and direction can be obtained. The average wind speed is defined as:

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$$S_A = \frac{1}{N}\sum_{i=1}^{N} s_i \tag{1}$$

And the average wind direction is defined as:

$$\theta_A = \frac{1}{N}\sum_{i=1}^{N} \theta_i \tag{2}$$

Where

| | |
|---|---|
| $S_A$ | Arithmetic mean of wind speed |
| $\theta_A$ | Arithmetic mean of wind direction |
| $s_i$ | *i*-th sample of wind speed |
| $\theta_i$ | *i*-th sample of wind direction |
| N | Total number of sample within an interval |

This method is simple and easy to implement in average wind speed and direction calculation, but it lead the result to some problems. One of them is average wind direction problem. Wind direction is reported as azimuth degrees and is a circular function with the values between 0 and 359 degrees. The wind direction is discontinued at the beginning/end of the scale. The discontinuity of the scale will cause problem for arithmetic mean method. As an example the wind blew half the time from $359^0$ and the other half from $1^0$. This method will give the mean direction of $180^0$. Mathematically, this is correct, but the correct answer should be $0^0$.

*B. Scalar Average Method*

The scalar average method is similar to arithmetic mean method, but it just take horizontal component of the wind vector to calculate average wind speed, and uses a special processing method to compute a valid mean value to overcome the average wind direction problem faced by arithmetic mean method.

The scalar average wind speed ($S_s$) compute as follow:
Given:

$u_i$ signed magnitude of horizontal component of wind speed vector

$$S_s = \frac{1}{N}\sum_{i=1}^{N} u_i \tag{3}$$

To overcome degree discontinuity problem from $359^0$ to $0^0$, a single pass procedure developed by Mitsuta is recommended. The method assumes that the different between successive wind direction samples is less than 180 degrees. To ensure that, a sampling rate of once per second or more should be used. Using Mitsuta method, the scalar mean wind direction is computed as:

$$\theta_s = \frac{1}{N}\sum_{i=1}^{N} D_i \tag{4}$$

Where

$D_i = \theta_i; for\ I = 1$
$D_i = D_{i-1} + \delta_i + 360; for\ \delta_i < -180\ and\ I > 1$
$D_i = D_{i-1} + \delta_i; for\ |\delta_i| < 180\ and\ I > 1$
$D_i = D_{i-1} + \delta_i - 360; for\ \delta_i > 180\ and\ I > 1$
$D_i\ is\ undefined\ for\ \delta_i = 180\ and\ I > 1$
$\delta_i = \theta_i - D_{i-1}; for\ I > 1$
$\theta_i\ is\ azimuth\ angle\ of\ the\ wind\ direction\ for\ i^{th}$

There are some cautions apply to the determination of the scalar mean wind direction using equation above:

- If the result is less than zero or greater than 360 degrees, increment of 360 degrees should be added or subtracted until the result fall within 0-359 degrees.
- Erroneous results may be obtained if this procedure is used to post process sub hourly averages to obtain an hourly average. This is because there can be no guarantee that the different between successive sub-hourly averages will be less than 180 degrees.

*C. Vector Average Method*

Vector average method is a method that can give a reasonably reliable result on average wind speed and direction. The wind speed is decomposed into x and y components which corresponding to east and north respectively and calculation is done base on these two components. This method will eliminate the problem of discontinuity issue of the scale.

Given:

| | |
|---|---|
| $s_i$ | *i*-th sample of wind speed |
| $\theta_i$ | *i*-th sample of wind direction |

$$\begin{aligned} x_i &= \sin\theta_i \\ y_i &= \cos\theta_i \\ u_i &= s_i x_i \\ v_i &= s_i y_i \end{aligned} \tag{5}$$

$x_i$ and $y_i$ are the unit vectors component that correspond to east and north respectively, and $u_i$ and $v_i$, are the wind speed vector components. These vector components are summed over the averaging period and the vector averages are computed at the end of averaging period:

Average unit vector (*x* component):

$$X = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{6}$$

Average unit vector (*y* component)

$$Y = \frac{1}{N}\sum_{i=1}^{N} y_i \tag{7}$$

Average wind speed vector (*x* component)

$$U = \frac{1}{N}\sum_{i=1}^{N} u_i \tag{8}$$

Average wind speed vector ($y$ component)

$$V = \frac{1}{N}\sum_{i=1}^{N} v_i \tag{9}$$

The $X$, $Y$, $U$, $V$ terms are used to compute the vector average wind speed ($S_v$) and vector average independent wind direction ($\theta_v$). The resultant vector average wind speed and vector average independent wind direction are:

$$S_v = \sqrt[2]{(U^2 + V^2)} \tag{10}$$

$$\theta_v = \tan^{-1}(Y/X) \tag{11}$$

Additional check need to be performed for the value of $X$ is nonzero and the direction of $Y$ and $X$ for the full 360 degree range.

The vector average independent wind direction computes average direction based on unit vector. It did not take in count of wind speed. In some condition, this method is not suitable for average direction calculation. Vector average component wind direction is another approach to compute average wind direction where it used wind speed as weight for average direction calculation as equation below:

$$\theta_{vc} = \tan^{-1}(V/U) \tag{12}$$

## III. STANDARD DEVIATION

The standard deviation of the wind direction $\sigma_\theta$, is based on the time series of wind direction measurements, $\theta_i$ and the average wind direction, $\theta_v$. A formal definition of $\sigma_\theta$ is:

$$\sigma_\theta^2 = \frac{1}{N}\sum_{i=1}^{N}\Delta_i^2 - \left[\frac{1}{N}\sum_{i=1}^{N}\Delta_i\right]^2 \tag{13}$$

With $\Delta_i$ defined such that each $|\Delta_i|$ is the smaller of $|\theta_i - \theta_v|$ and $2\pi - |\theta_i - \theta_v|$. Calculating this exactly requires two passed over the data, first calculate $\theta_v$, and then to find $\sigma_\theta$,

There are several methods for calculating the standard deviation of the wind direction that uses single pass method so that data can be processed in real time without storing all the wind samples in memory. Several single pass methods are compared by Yamartino and a method developed by him was found to provide excellent result for most cases. The Yamartino method is given in the following:

Given:

$X$ Average unit vector (x component)

$Y$ Average unit vector (y component)

$$\sigma_\theta = \sin\left[\varepsilon\left(1 + \frac{2}{\sqrt[2]{3}}\varepsilon^3\right)\right] \tag{14}$$

Where

$$\varepsilon = \sqrt[2]{1 - (X^2 + Y^2)} \tag{15}$$

## IV. RESULT

To verify the calculation method, an experiment had been performed. Basically, this experiment is using a device to collect the wind information for performing several computational methods of wind speed and direction. The wind speed and wind direction information was obtaining using Weather Station PB100 from AIRMAR Technology Corporation. Meanwhile, a signal processing electronics board and its firmware had been developed too.

PB100 is an instrument that provides wide range of weather information. This instrument will continuously transmit out NMEA0183 sentences which content all commonly seen meteorological data. The main sentence use in this experiment is $WIMDA. This sentence content 20 meteorological information with 2 amongst them is wind speed and wind direction.

Graphs are plotted based on same set of wind data which is captured during 20 October 2009, 10am to 5am with sampling rate one sample per second. Average values are calculated every ten minutes interval. There are four graphs plotted. Figure 1 shows the arithmetic average wind speed versus time. Figure 2 shows arithmetic average wind direction versus time. Figure 3 and 4 present scalar average wind speed and direction. Vector average wind speed and vector average wind direction are shown in Figure 5 and Figure 6 accordingly. For vector average wind direction, there are two series plot at the same graphs which is vector average independent wind direction and vector average component wind direction. Both series will have different if average wind speed is near 0 m/s because of wind speed will be taken as weight in vector average component method which explained in part III, equation (12). Due to it was a windy day on 20 October 2009, both series shows a very similar pattern at final result.

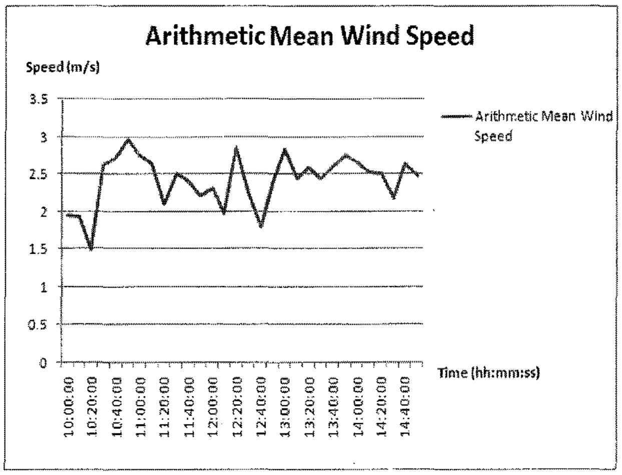


Fig. 1. Arithmetic Mean Wind Speed VS Time.

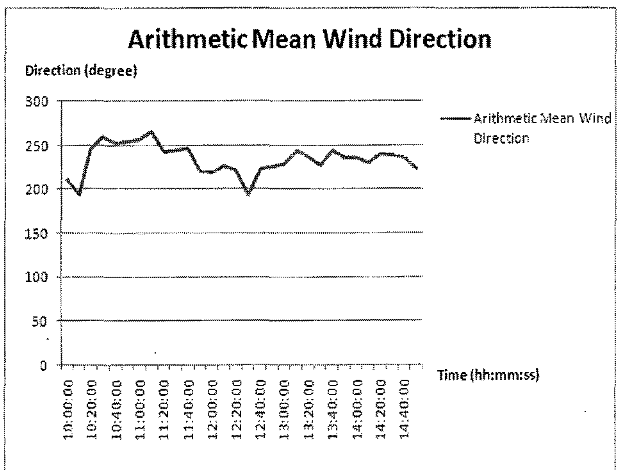


Fig. 2. Arithmetic Mean Wind Direction VS Time.

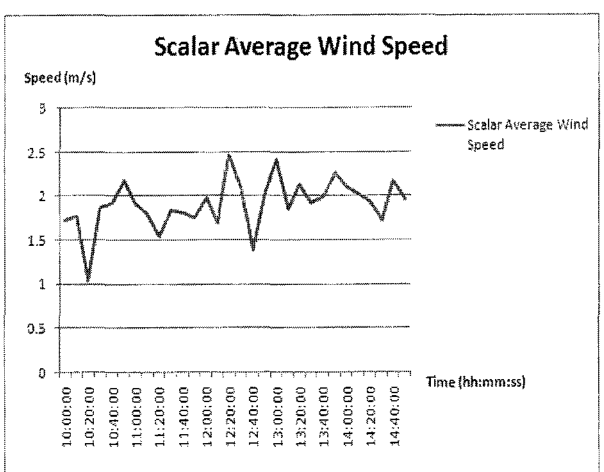


Fig. 3. Scalar Average Wind Speed VS Time.

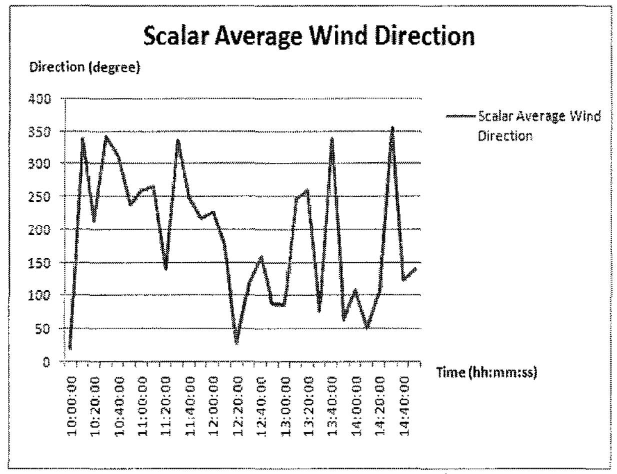


Fig. 4. Scalar Average Wind Direction VS Time.

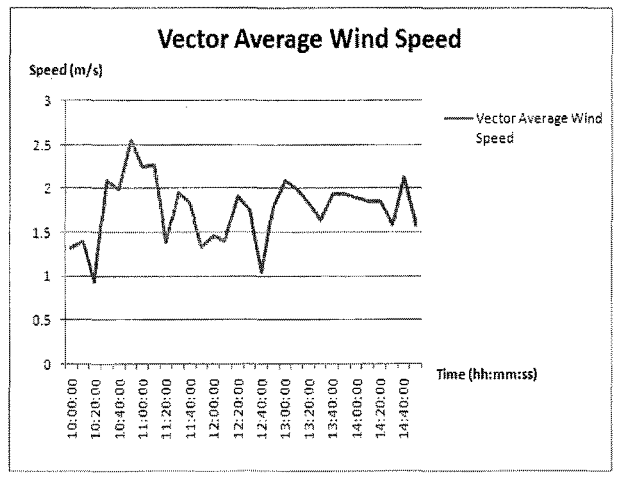


Fig. 5. Vector Average Wind Speed VS Time.

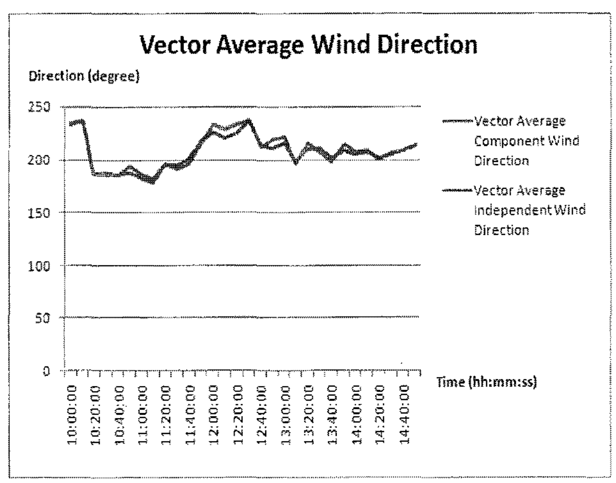


Fig. 6. Vector Average Wind Direction VS Time.

Figure 7 shows the comparison between arithmetic mean and vector average wind speed calculation methods. Only these two methods are compared due to they are implemented in a buoy system which will be discuss in next chapter. Since arithmetic mean do not take wind direction in count during the calculation, hence the arithmetic mean wind speed is always greater than the vector average wind speed. However, usually it is usually only a few percent larger than vector average method and it serves as a backup measurement if the compass or vane fails and vector average method is invalidated.

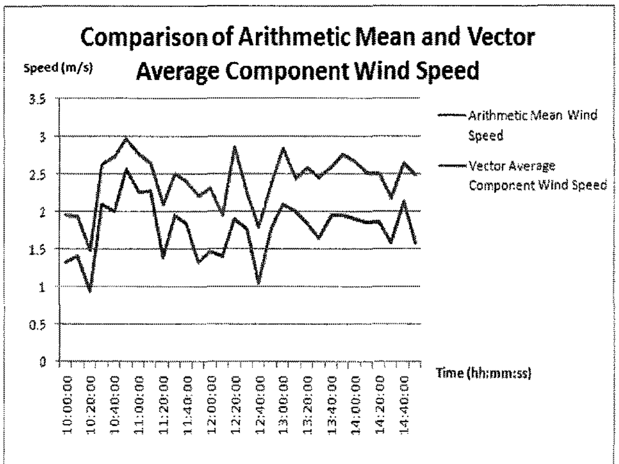


Fig. 7. Comparison Chart between Arithmetic Mean and Vector Average Mean Wind Speed

## V. IMPLEMENTATION

Among these three methods, arithmetic mean and vector average are implemented in marine buoy. The function of this buoy is to collect meteorological information and send the data back to base station via TCPIP, satellite email and short message system. Data includes average vector wind speed and direction information. Scalar vector method was not chosen to implement in this buoy due to complicated calculation on average wind direction. Too much condition to be fulfilled and there is also limitation in calculating average wind direction. Vector average method was implemented in this buoy due to reasonable complexity from the view of microcontroller processing power and most important is the accuracy of the result, which it can provide a very accurate average data. Besides, arithmetic mean was also implemented in this buoy, but not for final data output to base station. It is just serve as backup data and stored in SD card memory for debugging purpose.

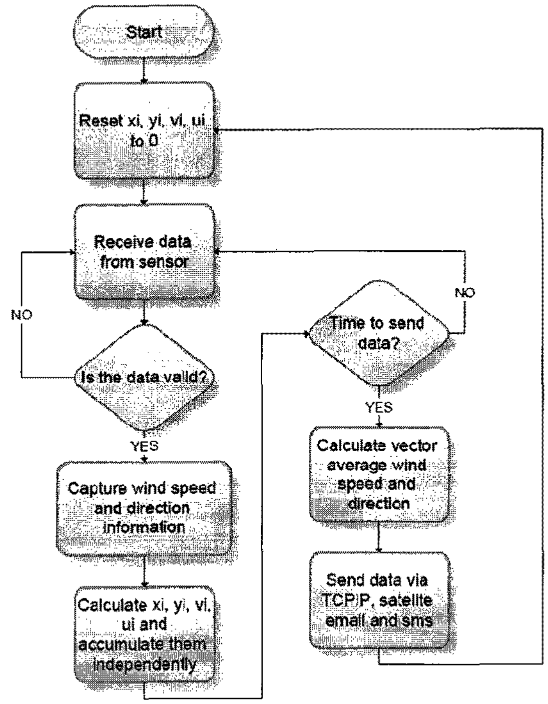


Fig. 8. Flow Chart for Vector Average Wind Speed and Direction Calculation

Figure 8 illustrates the flow chart of the average calculating algorithm in actual buoy system. Extra care need to be taken during calculating $\theta_{vc}$ before sending the data. Due to wind direction is measured using azimuth degree where reference to true north and increase in clockwise direction, but standard trigonometry function that provided by compiler library is based on mathematics standard which reference to east and degree increase in counter-clockwise direction. Hence, a conversion needs to be performed to convert the resultant degree from standard degree measurement to azimuth degree standard. The conversion can be done using equation (16), where $\theta_{vc}$ is calculating using equation (12).

$$\theta_{azimuth} = 90 - \theta_{vc} \tag{16}$$

The buoy was successfully moored and some data were captured at base station. Data were captured from 18:50:00, 22 October 2009 until 09:30:00, 23 October 2009. Wind speed was calculated using vector average method where wind direction was computed using vector average component method. Figure 9 shows the average wind speed versus time where figure 10 shows the average wind direction versus time.

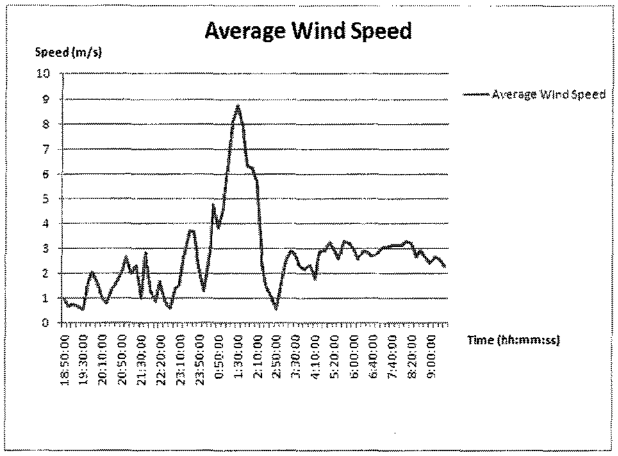


Fig. 9. Average Wind Speed VS Time.

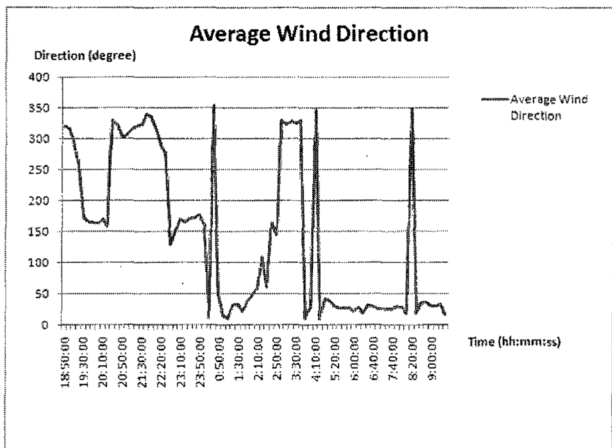


Fig. 10. Average Wind Direction VS Time.

## VI. CONCLUSION

In this paper, it introduces some average wind speed and direction calculation methods, and a brief introduction on each method's problem and limitation. For implementation details, refer to part IV which contain the graph for all three methods which are arithmetic mean, scalar average and vector average method. Among these three methods, vector average method is a better solution and it is recommended in computing average wind speed and direction. This method can overcome wind direction discontinuity problem compare to the other two methods, and able to provide more accurate result.

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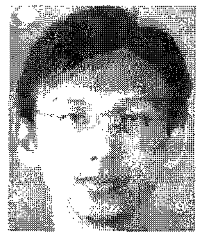

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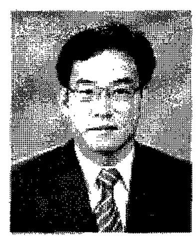

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