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GUIDANCE ON THE ESTABLISHMENT OF ALGORITHMS FOR USE IN SYNOPTIC AUTOMATIC WEATHER STATIONS

- Processing of Surface Wind Data -

by D. Painting (UK)

1 Definitions.

Wind velocity is a three-dimensional vector quantity. For most surface applications the horizontal component only of the wind vector is considered and it is usually described in polar co-ordinates by the scalar quantities direction and speed.

2 Requirements

2.1 Wind speed is reported to a resolution of 0.5 ms^{-1} or in knots and for synoptic purposes it should represent an average over ten minutes at an effective height of 10 m above open level ground. Wind gust is reported to the same resolution and should represent a gust duration of around 3 seconds. The accuracy requirement for both average wind speed and wind gust is $\pm 0.5 ms^{-1}$ up to 5 ms^{-1} and $\pm 10\%$ above 5 ms^{-1} over a range of 0 to 75 ms^{-1}.

2.2 Wind direction, defined as the direction from which the wind blows, is reported in degrees to the nearest 10 degrees and is measured clockwise from geographical north. For synoptic purposes the reported direction should represent an average over 10 minutes.

3 Wind Characteristics

Wind is highly variable in space and time with small scale fluctuations superimposed upon a larger organised flow. Spectra of horizontal wind components have been obtained at many sites. These spectra generally exhibit a rather wide gap centred at a period of about 30 minutes separating synoptic (macroscale) motion from microscale motion. For synoptic purposes a ten minute averaging time is chosen to smooth out the small scale fluctuations so that the reported wind generally represents synoptic scale features. The spectrum of small scale fluctuations, or gust spectrum, is characterised by a peak at periods around 2 minutes and falls off with increasing wave number (frequency) according to a -5/3 power law. Wind extremes are mainly used for warning purposes and for climatology of extreme load on buildings and constructions. Gusts that persist for about three seconds correspond to a wind run of the order of 50 to 100 m in strong wind conditions. This is sufficient to engulf structures of ordinary size and to let them 'feel' the full load of a potentially damaging gust; hence the recommendation that reported gusts should represent the peak of the wind speed averaged over about 3 seconds.

4 Sensor Characteristics

4.1 There are many types of wind sensor, however the overwhelming majority in operational use are of the propeller/vane or cup/vane types.

4.2 Cup and propeller anemometers for the measurement of wind speed can be characterised by their 'response length' which is a constant dependant on mechanical and geometrical factors. In general cup and propeller anemometers respond more quickly to increasing wind speed than to decreasing wind speed so that computed averages of a fluctuating wind generally overestimate the time averaged speed.

Cup anemometers are susceptible to vertical fluctuations and this also can cause 'overspeeding'. The combination of these effects, which can be as much as 10% for some designs in gusty conditions, can be minimised by choosing fast response anemometers.

The response of a cup or propeller anemometer to a step change in input speed ΔU takes the 'first order' form:

FOREWORD

The tenth session of the Commission for Instruments and Methods of Observation (CIMO) decided that guidance material for all appropriate variables should be produced and published for the guidance of Members of WMO. Accordingly, this publication contains algorithms for processing of data obtained from wind sensors for use in automatic weather stations reporting a synoptic message.

This material has been prepared by Mr. D. Painting of the United Kingdom, a member of the CIMO Working Group on Surface Measurements, for use by Members. I am most grateful to him for this valuable work.

(Jaan Kruus)
President of CIMO

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Cup anemometers are susceptible to vertical fluctuations and this also can cause 'overspeeding'. The combination of these effects, which can be as much as 10% for some designs in gusty conditions, can be minimised by choosing fast response anemometers.

The response of a cup or propeller anemometer to a step change in input speed ΔU takes the 'first order' form:

$$n = K(U + \Delta U\ (1-\exp{}^{-t}/_{\tau})$$

where n is the output revolutions per second
- K is a constant
- U is the initial wind speed
- t is the time in seconds
- τ is the "time constant" ie the time required for the anemometer to respond to 63.2% of the step change
  - τ varies inversely with wind speed ie $\tau u=d$ the distance-constant or response length of the anemometer which is typically between 2 and 5 m.

4.3 The electrical outputs of cup and propeller anemometers suitable for synoptic AWS are generally either frequency (or pulse) type or direct current/voltage type.

In the case of a frequency output, interface circuits may be employed to convert to direct current or voltage (dc) or the frequency may be counted directly over a suitable time interval. The required sampling intervals for frequency outputs are discussed in 5.7.

4.4 Wind vanes respond to changes in wind direction according to a second order differential equation. The response is characterised by overshoot and oscillation about the true position, the amplitude of the oscillation decreasing approximately exponentially with time. In general the characteristics of wind vanes are described by the "undamped natural frequency" and the "damping ratio". The damping ratio is the ratio of the actual damping of the vane to the critical damping. (A critically damped vane exhibits no overshoot or subsequent oscillation.) Practical wind vanes have damping ratios between 0.3 and 0.7 which give a reasonably fast response without excessive overshoot. A suitable undamped wavelength is less than 10m which will allow a comparable response to the speed sensor with characteristics as suggested in 4.2.

4.5 The electrical outputs of wind vanes are typically direct current or voltage (dc) (eg using a potentiometric transducer), ac synchro types or digital encoder types. Except where a dc or digital output is provided it is usual to employ an interface circuit to provide a dc output for further processing in an AWS system.

5 Sampling

5.1 The considerations which govern sampling apply equally to wind direction and speed. In most practical systems the sampling of wind speed dictates the system design owing to the requirement to measure wind gust.

5.2 Since virtually all AWS systems now employ automatic digital processing the factors applying to digital systems only will be considered here.

5.3 It is important to realize that input data sampling should be designed to preserve the required information content of the measured variable taking into account the post sampling processing that will be employed. Theoretically, to preserve required input data, it is merely necessary to sample at the 'Nyquist' frequency (ie at twice the highest frequency present in the input variable). This implies that input frequencies should be contained within suitable limits and filters are usually employed to achieve this aim.

In practical systems the input presented to the sampler is constrained by the transducer characteristics and any interfaces and filters employed. Many systems are designed such that the input variable response is governed mainly by a low pass filter which does not have a sharp cut off above unwanted frequencies.

Hence for a system employing a simple (first order) low pass filter with time constant τ it is recommended that the sample interval is τ seconds for the purpose of computing 10 minute <u>averages</u>.

5.4 For the measurement of gust speed a higher rate of sampling is necessary if the true gust speed indicated by the sensor is to be measured (as opposed to that estimated statistically). This requirement is easily recognised when studying the output of a real wind sensor after smoothing with a one second time constant filter as shown in figure 1.

Even at the moderate speeds illustrated it would not be possible to meet the 0.5 ms^{-1} accuracy requirement by using 1 second samples For practical purposes in the example shown samples should be taken at least 4 times per second to allow accurate gust measurement.

5.5 Rapid sampling of sensor data also allows a measure of automatic quality control of input data. This point will be discussed further in 6.1.

5.6 Data from sensors which exhibit markedly non-linear responses should be linearised as close to the sensor as possible in the processing chain. Failure to observe this requirement may lead to serious errors in computed averages. This is somewhat analogous to the errors obtained through the asymetric response of the cup or propeller anemometer.

5.7 The recommended input sampling algorithm may be summarized as follows.

a. DC type

i. Linearise output from sensor

ii. Pass linearised output through suitable (analogue) filter with time constant τ(eg low pass filter with time constant 1 sec).

iii. Sample data at $\tau/4$ second intervals (for gust measurement) or τ seconds if averages only required.

b. Frequency type

i. Measure frequency over intervals of T seconds where T is the gust averaging time. If gust measurement is required make samples overlap at steps of T/12 (ie with T = 3 seconds periods overlapping by 0.25 seconds (see fig 2)).

ii. Linearize data if necessary.

The data thus sampled are suitable for further processing to produce maximum gusts and averages with automatic quality control.

6 Data processing

6.1 Quality control. The main purpose of automatic quality control at the sensor location is to detect and remove obvious errors (due to instrument malfunction) and/or to remove noise (eg electrical 'spikes') from a sensor input chain.

Sensor data should therefore be subjected to two tests.

i. Range check (to reject 'impossible' values)

ii. Rate of change check (to remove noise).

An algorithm which is suitable for removing spikes is shown in figure 3.

For wind direction data the rate of change check is not recommended as wind direction is usually presented as an average value.

6.2 Data averaging. Two methods of averaging are commonly employed (a) 'arithmetic' averaging in which all values over the specified averaging period are given equal weight and (b) 'exponential' averaging in which values are exponentially weighted with time (highest weight to most recent samples).

6.3 For wind data averaging it is useful to consider the most efficient (in terms of computation time) methods of averaging since AWS processing power is often rather limited. Also owing to the discontinuity (0° - 360°) in wind direction data it is worth considering algorithms which are equally suitable for wind speed and wind direction and can give a 'continuous' output (a characteristic of the exponential averager) or a discontinuous output (characteristic of the arithmetic averager).

6.4 The suggested algorithms are as follows

i. For arithmetic averaging

$$\bar{Y}_n = 1/n\ (Y_n - \bar{Y}_{n-1}) + \bar{Y}_{n-1}$$

$n = 1$ to N

where $\bar{Y}_n$ is the average of n samples
Y_n is the nth sample
$\bar{Y}_{n-1}$ is the average of n-1 samples
$\bar{Y}_N$ is available after N samples are taken over a period T seconds

ii. For exponential sampling

$$\bar{Y}n = k\ (Y_n - \bar{Y}_{n-1}) + \bar{Y}_{n-1}$$

where $k = (1-\exp -t/\tau)$
t is the sample interval
τ is the time constant of the averager $= T/3$
$\bar{Y}_n$ is the average after sample n
$\bar{Y}_{n-1}$ is the previous average (ie after sample (n-1))

note $\bar{Y}_n$ (the average wind speed) is available after <u>every</u> sample and is equivalent to $\bar{Y}_n$, the arithmetic average after N samples.

if $\tau \gg t \quad k \approx \frac{t}{\tau}$

6.5 Wind direction discontinuity can be dealt with readily by noting that the value $(Y_n - \bar{Y}_{n-1})$ can take an absolute value greater or less than 180°; accordingly 360° can be added or subtracted to enable the next average value of direction to be computed. The full algorithm is illustrated below.

i. Compare new sample with previous computed average

ie $(Y_n - \bar{Y}_{n-1}) = E$ (say)

ii. If E is greater than 180° subtract 360° from E

If E is less than -180° add 360° to E

iii. Compute new average (using algorithm given in 6.4).

iv. If new average is greater than 360°, subtract 360°

If new average is less than 0, add 360°

6.6 An alternative averaging method for wind direction is to convert the measured direction into components of a unit vector and sum the components individually. The mean direction is then given by the resultant angle of the mean vector produced. This process is computationally inefficient compared with the version given in 6.5 above and is not recommended.

6.7 Height Correction

Where in open terrain the anemometer is exposed at a non standard height the mean wind speed can be adjusted to provide an estimate of the wind at 10 m above ground using a logarithmic formula. A suitable form is given below.

$V_h = V_{10} (0.233 + 0.656 \log_{10} (h + 4.75))$ where V_h is the wind speed at height h metres and V_{10} is the wind speed at 10 m above ground.

In general it is not necessary to correct gust speed for exposure height.

7 Concluding Remarks

The recommendations contained here are intended to provide basic guidance for the design or specification of wind processing algorithms for operational synoptic surface wind sensor data. It should be stressed that the algorithms do not compensate for a badly designed or poorly exposed wind sensor. They are designed to preserve the integrity of the sensor outputs as presented to the input of an AWS system. The guidance applies to the majority of sensors in current use worldwide and, if used, will help to ensure that reported data from different designs of sensor and wind measuring systems are compatible with one another and that sensor accuracy is not degraded by the processing system.

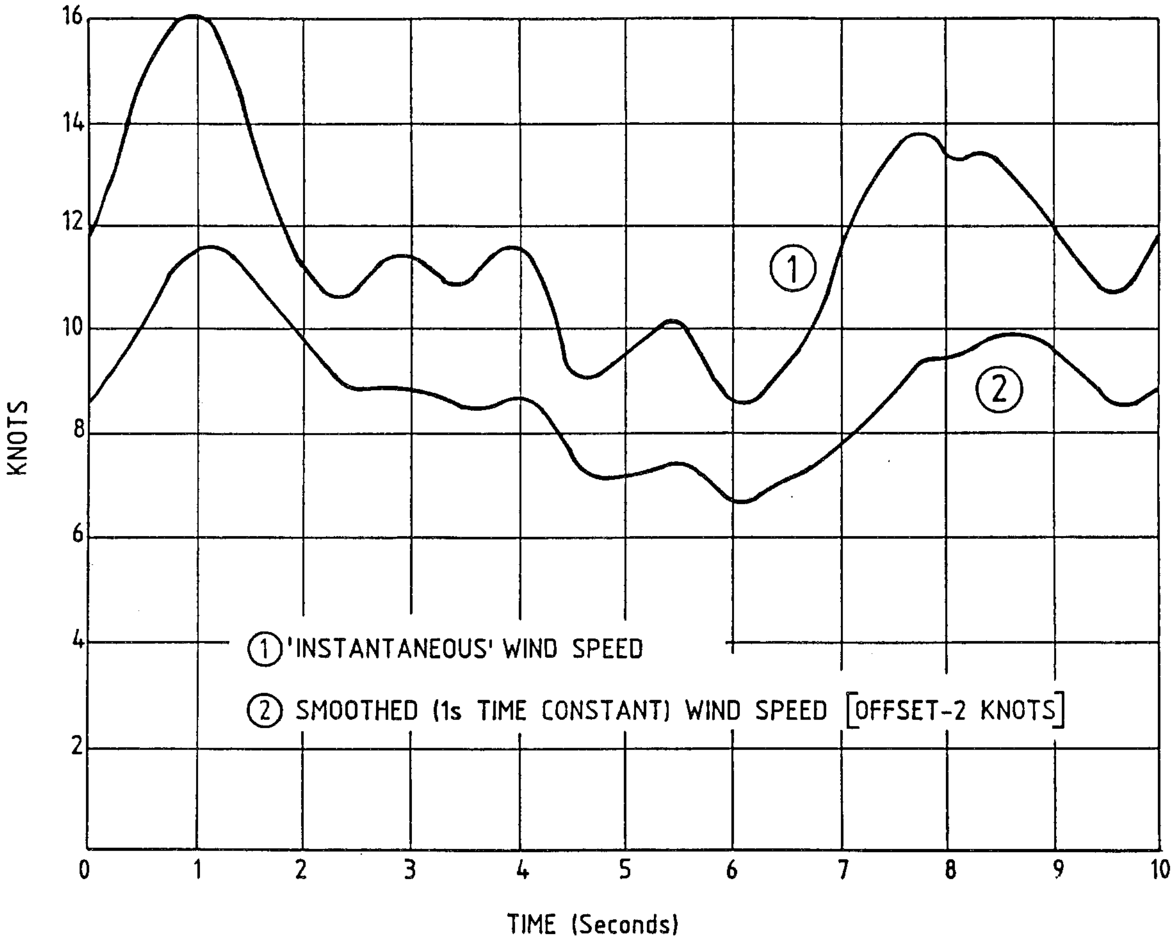

Figure 1. TYPICAL WIND RECORD.

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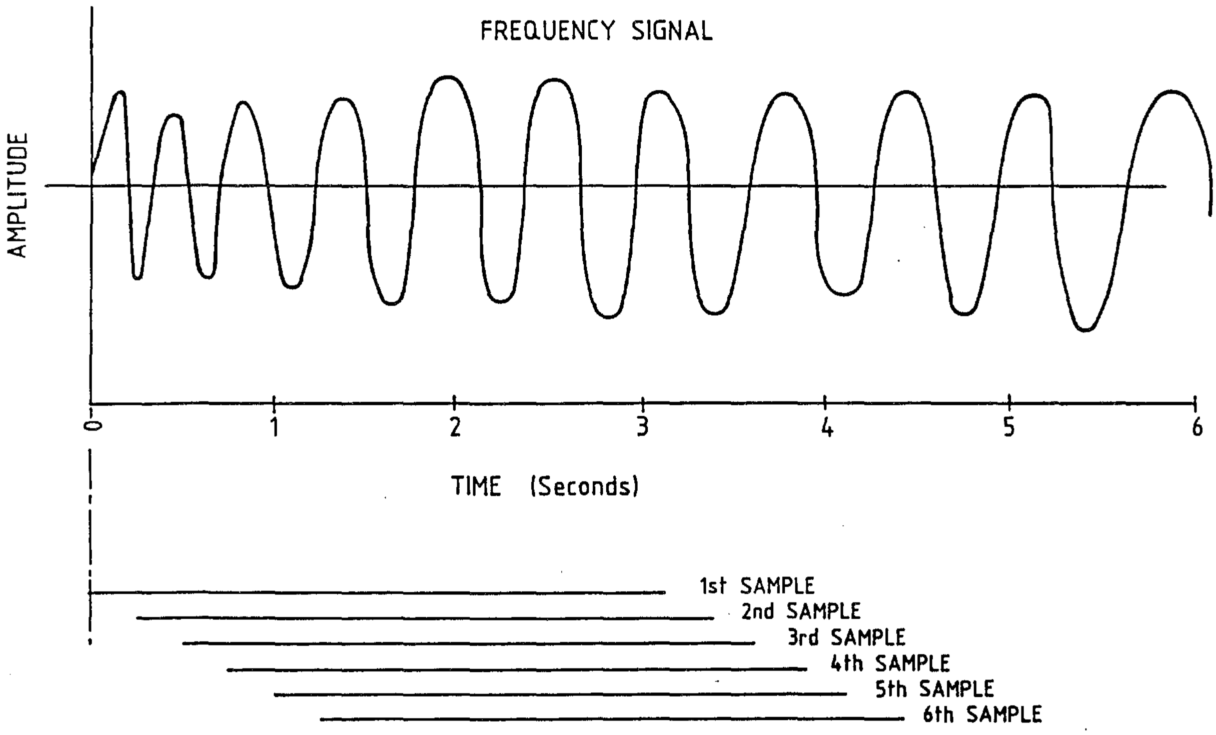

Figure 2. FREQUENCY INPUT SAMPLING.

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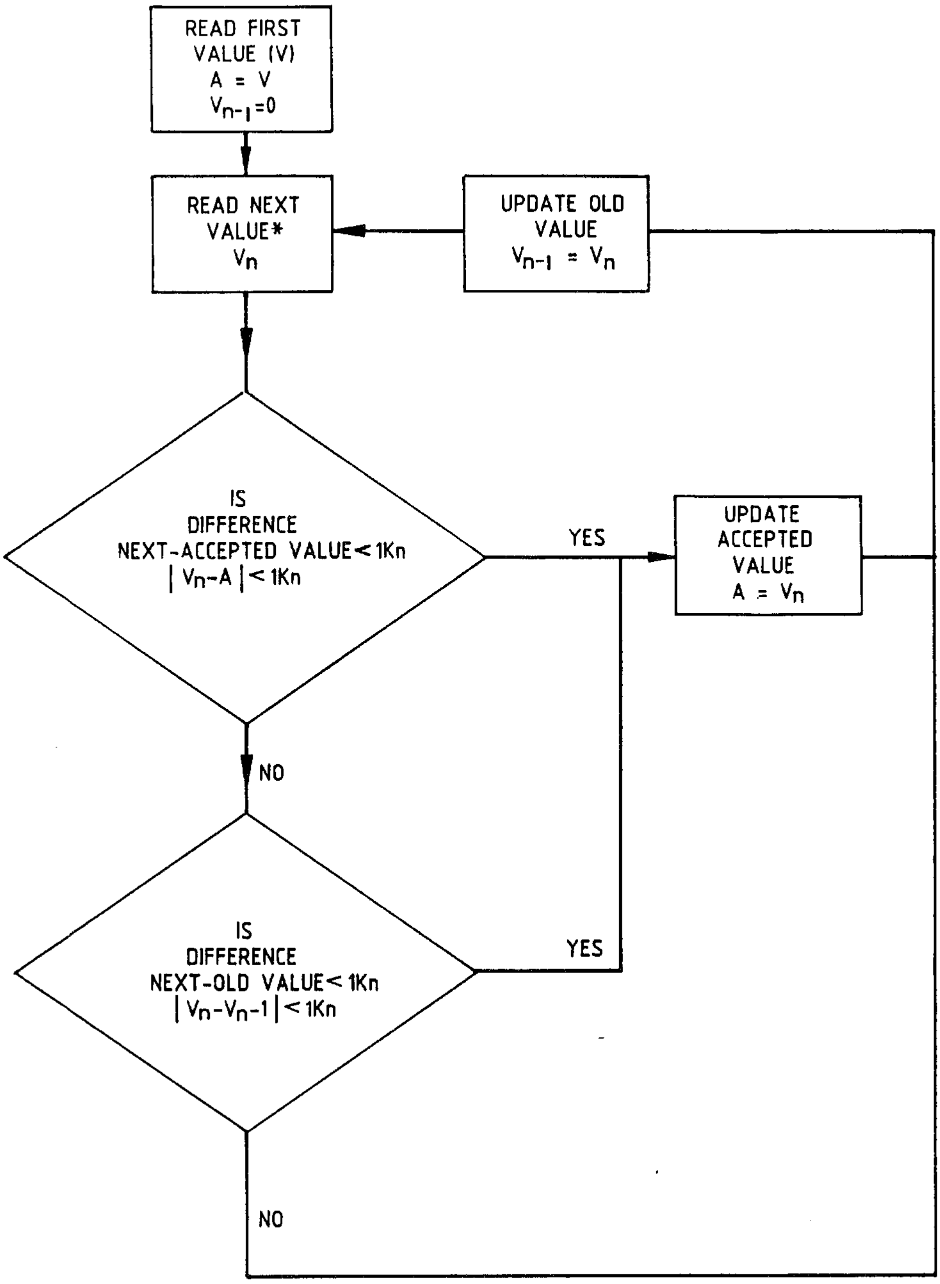

* Range check assumed already applied.

Figure 3. QUALITY CONTROL OF WIND SPEED.

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