Sensors for Monitoring Present Weather Conditions

WEATHER MONITORING

Dr. Richard Ellis, Research Engineer, Campbell Scientific Ltd., 80 Hathern Road,
Shepshed, Leicestershire LE12 9GX, UK
Email:r.ellis@campbellsci.co.uk Tel:+44 (0)1509 601141 Fax:+44 (0)1509 601091 Website:www.campbellsci.co.uk

Figure 1. The Campbell Scientific PWS100 being installed.

Introduction

The World Meteorological Organisation (WMO) defines present weather as a description of the weather phenomena occurring at the time of observation [1]. The definition of present weather includes a description of the form of precipitation and measurements of visibility. In many applications, in particular meteorological and airport reporting, a standard scale of events is used by an observer to describe the weather. Such reports are however subjective in nature and depend on a multitude of human factors which can vary over time or from observer to observer, and so accuracy and repeatability can be questionable. In many cases the use of automated equipment can prove to be beneficial as the classification of weather events is more objective and can be more frequently reported without human error. However, it is to be noted that automated sensors used for present weather reporting cannot describe all aspects of the current weather conditions and so there is a separate scale of events for automated measurements. The use of automated present weather systems are however much more cost effective over time than human observations and can integrate a variety of sensor measurements to categorise the present weather conditions. Such systems have great benefit in remote and hostile locations where human observations are not practicable and are also used to augment manned weather observations.

Many techniques have been used in automated present weather sensors (PWS) in the past including light scatter meters and light occlusion meters. The first of these uses a light source, usually an LED, to illuminate a detection volume. A detector is placed off axis to the light source to capture any scattered light from the volume which comes from falling precipitation particles or from fog or mist. Individual particles give rise to short bursts of light at the detector and fog or mist gives a more uniform increase in measured light over time. The main drawback of these scatter based instruments is lack of accuracy in measuring individual particle parameters, such as the size or velocity, especially if precipitation particles fall obliquely through the beam or have differing scattering characteristics. This means that identifying what type of precipitation is falling through the volume is usually not possible without the integration of other sensors to measure temperature or the wetness of falling particles. Since particles are not accurately measured, standard meteorological sensor outputs such as rain rates and accumulation cannot be given with any accuracy and classification of precipitation into types such as light rain or moderate drizzle is unavoidably poor.

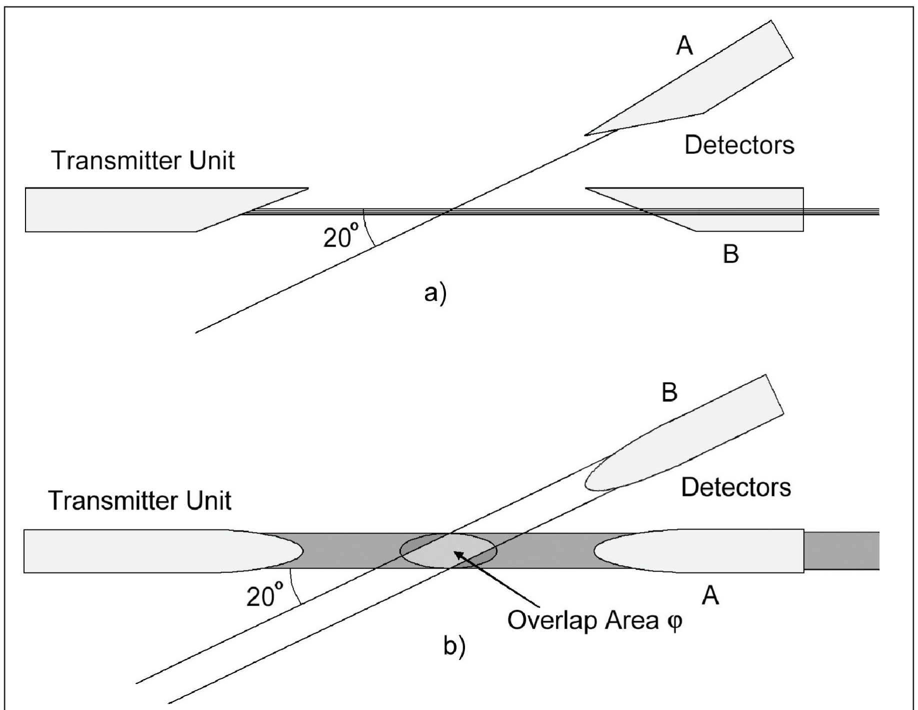


Figure 2. Transmitter and detector arrangement in a) side view and b) plan view.

The second type of sensor that has been used for monitoring present weather are those using more uniform detection volumes, usually formed of a horizontal light sheet from a laser light source through which a particle may pass. A detector is then placed in the path of the light beam and any particle falling through the beam will occlude the light and give rise to a brief dip in measured light intensity. Such sensors are often called distrometers as they are used to measure the distribution of particle sizes. To give an estimate of the size and velocity of particles, these sensors use the width and amplitude of the detected light reduction pulses, however different precipitation types affect the light to different extents and often particles are misclassified. Another drawback of these sensors is that measurements of visibility cannot be done as small temporal variations in the light sheet intensity makes visibility estimation difficult.

Most sensor systems extrapolate an overall weather condition from measurements made over a very small area and so there is inevitably some uncertainty in the physical measurements from the detection volume that can lead to inaccuracies in weather classification and statistical output.

Latest technological development

In order to improve the physical measurement of weather phenomena a new present weather sensor has been developed which uses the principles of a technique known as phase Doppler anemometry (PDA) to look at precipitation and determine accurate size and velocity parameters. These parameters can then be used in a decision matrix to determine precipitation particle type and can be analysed over specified periods of time to give WMO code output corresponding to event type, precipitation rates, precipitation accumulation and drop size distributions amongst other output. The sensor also uses the same technique as forward scatter meters to determine visibility range.

The new PWS developed by Campbell Scientific Ltd., called the PWS100, is based on PDA technology which overcomes the shortcomings of the older type sensors. The PWS100 transmitter outputs a set of four parallel, horizontal infra-red light sheets spaced at 0.8 mm intervals in order to define a volume that is consistent. These periodic structured light sheets allow the measurement of the size and velocity of precipitation particles in the range 0.1 mm to 30 mm in diameter to within ± 5%. Figures 2a) and 2b) show the physical geometry of the transmitter and sensor units as shown in side and plan views respectively.

The detectors are able to receive light from a well defined region, φ, and at well defined angles. The two sensors are at angles of 20° to the optic axis of the light sheet generator, one deviated through 20° in the horizontal plane, the other 20° in the vertical plane. In this way, the magnitudes of the scattered signals are similar and contamination of the optics is minimal. Quasi-periodic Doppler burst signals are obtained from all types of precipitation particles falling through the volume. Frequency analysis is carried out on the measured signals for the calculation of velocity and particle size is calculated from the time shifted signals observed at the angle separated detectors.

This system is less susceptible to windy conditions than other PWS systems because only the vertical velocity is calculated due to the geometry of the detection volume. Systems such as the forward scatter meters cannot distinguish the direction of particle movement and thus give inaccurate measurements of vertical particle speed.

The PWS100 uses a high speed digital signal processor (DSP) to analyse the data in real time. Algorithms are implemented for the analysis of individual particles, to determine their size, velocity and a measure of the signal structure. The PWS system also measures temperature and relative humidity (RH) as additional parameters via a CS215 temperature and relative humidity probe connected directly to one of its SDI-12 ports. Fuzzy logic algorithms are used to classify different particles such as rain, snow and hail using multiple data tables for each type of detectable particle. This is an improvement over older technologies that use single non-fuzzy classification tables for all precipitation types. The output from the PWS100 can be stored on dataloggers in remote locations or can be collected remotely using a modem link or various types of networks via RS-232, RS-422 or RS-485. Figure 3 shows a station located at a UK Met. Office site, which is connected via a modem link.

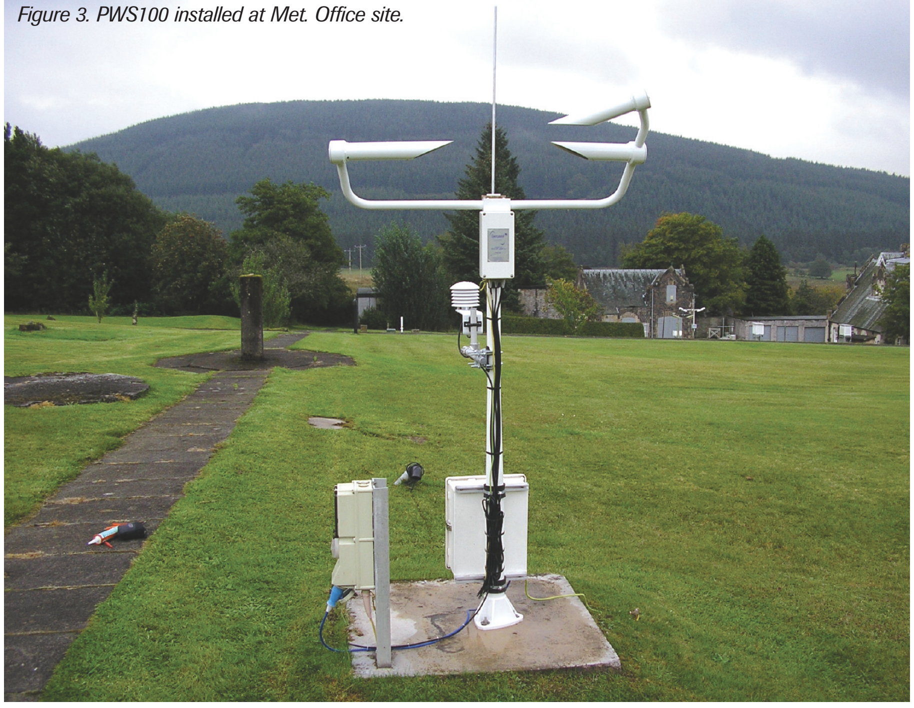
Mechanically the PWS100 is designed to operate in extreme conditions with a standard operating temperature range of -25°C to +50°C (optionally extended range -40°C to +70°C) and a relative humidity range of 0 to 100%. Heaters on the unit ensure that it remains free of ice in even the coldest conditions. The sensor uses industrial LEMO connectors for communications, power and auxiliary sensor connections and is rated to IP66.

Classification of precipitation

The relationship between the size and terminal velocity of rain and drizzle has been extensively researched and was given mathematical form in the model published by Best [2]. This relationship then defines the rain line, the proximity to which can help identify rain and drizzle events.

Solid precipitation, in contrast, shows quite different behaviour. In this case the definition of size becomes an issue in itself given the complex structures found in snow and other solid forms of

Figure 3. PWS100 installed at Met. Office site.



precipitation. Hanesch et al. [3] demonstrated that the terminal velocity correlates most closely with the dimension perpendicular to the motion of the particle. However, there is unavoidable variability in terminal velocity values for particles with the same size due to the differing particle densities, shapes and degree of riming.

Several boundaries can be defined corresponding to different types of particles and these are shown in figure 4 which shows output from a real rain event. The size-velocity distributions that help define the precipitation type are for the most part well separated, however further analysis of the signal structure provides another discriminating factor.

The signals obtained by the two PWS100 sensor heads differ considerably for rain and snow. Firstly, considering rain, detector A receives the quasi-periodic signal slightly before detector B because of the refraction of light through a liquid particle. The signals are cross-correlated and the position of the largest peak on the correlation (relative to the origin) gives a time delay which is relative to the particle size while the period gives a measure of the time delay which is relative to the particle velocity (essentially the frequency of the peaks in the burst signal).

Snow and other solid precipitation particles are usually multi-faceted and polycrystalline in nature and as such consist of randomly distributed scattering sites. Although whilst passing through the quasi-periodic light sheets these scattering sites give rise to a periodicity relative to the velocity at each sensor, the signals cannot be used in the same way to determine particle size as there is no fixed relationship between such scattered signals at different angles. However the size can be alternatively estimated, with an uncertainty of around $\pm$ 0.5 mm, from transit time measurements [4].

By measuring the signal peak height and the pedestal height, which can be obtained by removing all the high frequencies from the fast Fourier transform (FFT) of the signal and carrying out an inverse FFT on the resulting spectrum, a signal to pedestal ratio can be obtained. Liquid particles give rise to small pedestals and hence larger signal to pedestal ratios and solid precipitation produces large pedestals and hence smaller signal to pedestal ratios. This ratio is then used as part of the fuzzy logic algorithm for determining particle type.

Typical size and velocity measurements

Figure 4 shows size and velocity data collected using the PWS100 during a 16 hour period containing several light rain events that occurred on 5th July 2005 in Shepshed, England. During this time peak count rates of approximately 10 particles per second passing through the detection volume were observed and a peak rain rate of approximately 2 mmh^{-1} recorded. Many of the particles were of sizes corresponding to drizzle (<0.5 mm diameter) and very few were above 3 mm.

Typical drop size distribution

The distribution of drop sizes during a precipitation event can be recorded in bins of 0.1 mm from 0.1 mm to 30 mm. For example figure 5 shows a moderate rain event with the most prevalent particle size being 0.9 mm and a distribution which has few very small particles and a tail off towards larger particles up to 3 mm.

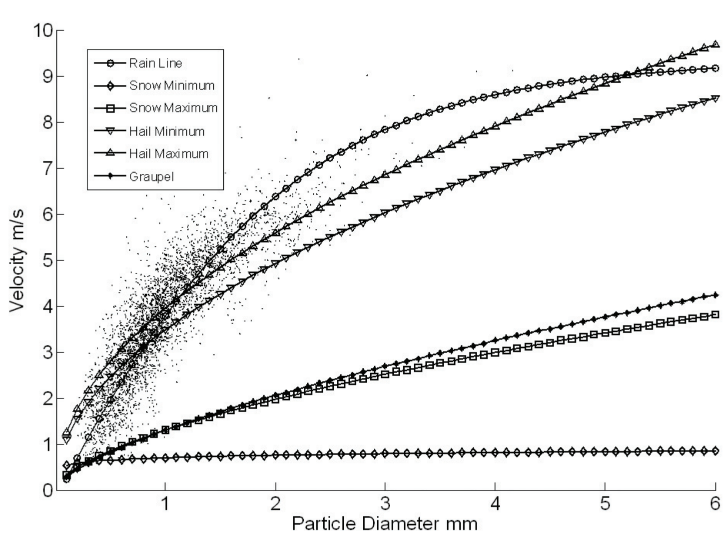


Figure 4. Size and velocity measurements for a rain event.

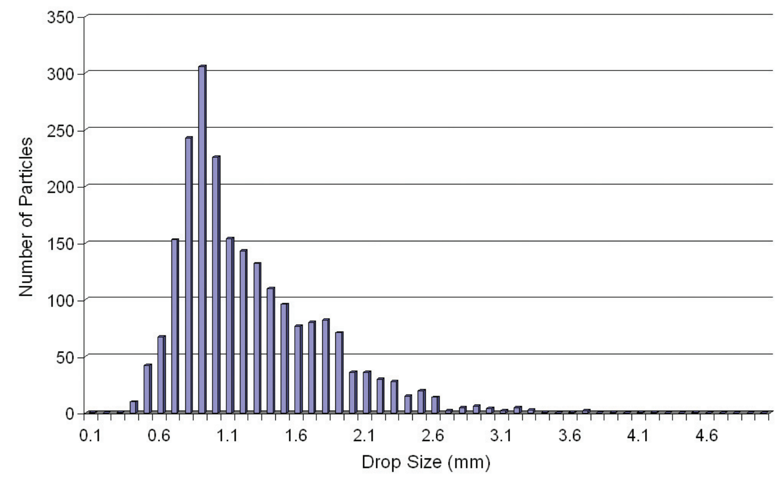


Figure 5. Graphical representation of drop size distribution

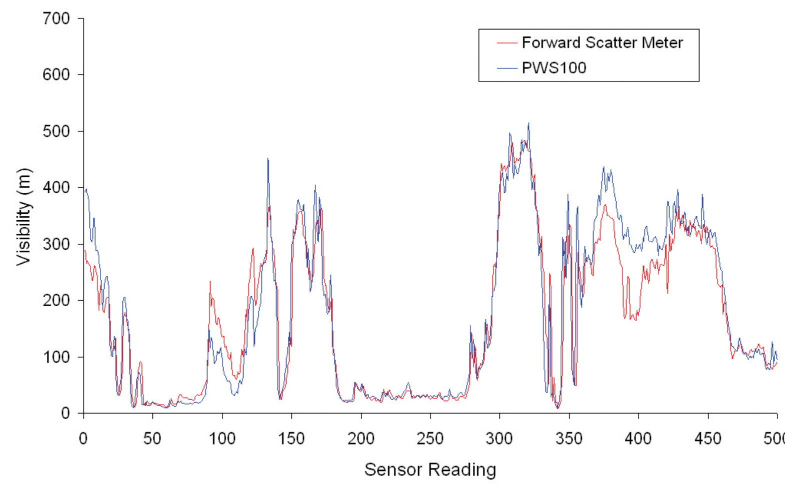


Figure 6. Visibility measurement.

Typical visibility measurements

The forward scatter technique for visibility measurements is well documented, with several commercial instruments available. The PWS100 has a basic geometry similar in many respects to these forward scatter visibility sensors. The detectors measure the mean intensity of the scattered light, I_s, and so an estimate of the scattering coefficient, k_s, can be made as it is assumed to have a directly proportional relationship. In this case the visibility for a 5% detection threshold, R_m, can be written,

$$R_m = 2.996 / K_s$$

And so,

$$R_m = R_0 / I_s$$

where the constant R_0 is determined from comparison with human observation. With small disperse particles this provides accurate visibility values, however if larger precipitation particles are falling the PWS100 can adjust the visibility value depending on the observed particle types, which improves the accuracy of measurement over stand alone visibility sensors.

Figure 6 shows visibility data collected using the PWS100 during the period 13:00 on the 24th January 2005 to 00:10 on the 28th January 2005 in Utah, USA, compared to another present weather sensor, using the standard forward scatter geometry, at the same location.

The data was evaluated as 10 minute averages taken every 10 minutes for 500 measurements over this period. The measurements agree well, though local fluctuations in fog density leads to some minor discrepancies. Over the range 0 to 10 km the PWS100 gives visibility readings with an accuracy of $\pm$ 10%.

Conclusions

The PWS100 present weather sensor is capable of measuring individual particle size and velocity parameters as well as outputting present weather type and other precipitation and visibility derived data. The latest DSP technologies are used so that real-time particle identification algorithms can be used to classify events as rain, snow, mixed etc… The sensor is robust and ideally suited to remote weather monitoring, being applicable for roadside, meteorological and research applications and being capable of giving various meteorological measurements such as drop size distributions, weather type and visibility, minimising the need for other meteorological equipment on site.

References

[1] WMO 1996 Guide to Meteorological Instruments and Methods of Observation (World Meteorological Organisation, Geneva)

[2] Best A C 1950 *Q. J. R. Meteorol. Soc.* 76 302-311

[3] Hanesch M, Waldvogel A, Schonhuber M and Randeu W L 1998 Fall Velocity and Shape Parameters of Solid Precipitation Particles *Conf. On Cloud Physics* 13A.6 (American Meteorological Society, Washington) 407-408

[4] Ellis R A et al. 2006 New laser technology to determine present weather parameters *Meas. Sci. Technol.* 17 1715-1722