Remote sensing best practice

Peter J M Clive

Technical Development Officer, SgurrEnergy Ltd
Address: 225 Bath Street, Glasgow G2 4GZ, Scotland
Email: peter.clive@sgurrenergy.com
Telephone: +44(0)141 227 1724

Abstract
Remote sensing technologies such as SoDAR and LiDAR have proved to be cost-effective methods of acquiring critical project datasets from locations that present access challenges. As a result they are increasingly being adopted in the offshore environment where their compact, portable and robust characteristics can be maximally leveraged to acquire data that previously would have represented greater cost or would not have been available at all. The codification of best practice in relation to remote sensing has made significant progress and currently is the focus of efforts made by, for example, the IEC, the IEA and MeasNet, among others. This process is providing both informative recommended guidelines and a regulatory framework of normative procedures which remote sensing practitioners will need to comply with to ensure, for example, the robustness of calculations of project uncertainty, representing in a complete and unbiased manner all sources of project uncertainty. This paper outlines the status of the regulatory environment regarding the use of remote sensing as well as discusses the benefits that accrue through compliance. In addition key sources of uncertainty are discussed and best practice described in the light of the developing normative framework.
Introduction
The constraints that apply to this conference paper in terms of length mean that it cannot serve as a single comprehensive stand-alone guide to best practice when operating remote sensing devices to acquire wind data for wind power applications. However, there is a rich and diverse literature already where sufficient guidance can be found. This paper should be viewed as a high level review, a sort of road-map through the existing literature detailing guidelines, recommendations, and normative standards relating to the use of remote sensing in the wind power industry. The author refers the reader to [2, 4, 6, 7, 9 and 11] for detailed discussions of best practice.

In addition, this paper will outline some general considerations which have an important bearing on the development of the regulatory environment governing the use of remote sensing in the wind power industry.

Figure 2: various models of LiDAR

What is remote sensing?
Remote sensing typically refers to the use of SoDAR and LiDAR. Some examples of these are shown in Figure 1 – 3. These use the interaction of laser or acoustic pulses with the atmosphere to acquire measurements. References [1 – 11] and the works cited therein provide a detailed description of their operating principles. These measurement principles differ from those represented by conventional mast mounted cup anemometry. The measurements themselves may therefore differ under certain circumstances. The standards and guidelines governing measurements in the wind power industry are written in terms of measurements made using IEC compliant cup anemometers whose performance is understood in terms of observations made at wind tunnel facilities that have been inspected and found to comply with national standards. Confidence in remote sensing devices requires that their performance can be understood in terms of the measurements that would have been made by these cup anemometers had they been deployed instead of the remote sensing device. However wind
tunnel facilities that are suitable for observing the performance of both cup anemometers and remote wind sensing devices are not available and so comparisons between remote sensing devices and reference instruments comprising mast mounted anemometers configured and calibrated in an IEC compliant manner are necessary.

Figure 3: Galion LiDAR

Remote sensing complements mast measurements, rather than replaces them. There are technical reasons for this arising from, for example, the complementarity of the different measurement principles and the differing degrees of autonomy and deploy-ability under the circumstances prevailing on site. However the most compelling argument for complementarity is economic. The objective of many measurement campaigns is to achieve the greatest reduction in project uncertainty for a given investment in data acquisition, and the way the costs of the different measurement techniques are structured leads to them being used in different roles. For example, the cost of a mast may be heavily weighted towards installation, in which case it makes financial sense to leave the mast in place to acquire one or two years of wind data for use in, for example, MCP studies. Remote sensing often represents a cumulative cost associated with equipment hire, resulting in the most advantageous cost-benefit accruing from shorter term deployments across multiple locations, exploiting the compact and portable nature of the devices to achieve objectives of the measurement campaign that may be more difficult or costly with a mast.

In general remote sensing needs to be used to acquire measurements that would be difficult, impossible, or even inconceivable with masts, in order to unlock the value of remote sensing. In many instances, if mast-like measurements are required, the most cost-effective way of acquiring them, from the point of view of the cost per percentage point reduction in project uncertainty, is to install a mast. Remote sensing is effectively used to undertake assessments that are beyond the limitations of masts, such as wind shear extrapolation across the entire rotor disc of a large wind turbine, or the horizontal extrapolation of wind resource across multiple proposed wind turbine locations.

Remote sensing devices are amenable to onshore and offshore use. There is a massive diversity of tools and techniques associated with remote wind speed sensing, including but not limited to

- “mast replacement” techniques such as Velocity Azimuth Display (VAD) and Doppler Beam Swinging (DBS),
- techniques that acquire data from regions not immediately above the device, such as arc/sector scans, position plane indicator (PPI) and range height indicator (RHI) scans, and
- multiple aperture, convergent beam, dual Doppler, bistatic techniques that are more suitable for complex terrain, such as crossed RHI (XRHI) and co-planar RHI configurations.
These techniques offer a huge scope for reducing project uncertainty and risk, both by directly addressing the contributions to project uncertainty that arise through the incomplete understanding of the variation in wind conditions across the site, and by the acquisition of critical site suitability information that may have otherwise remained undetected during the development phase, such as, for example, the incidence of wind shear anomalies like low level jets. However performance must be related to existing tools and techniques, such as cup anemometry. Nevertheless, best practice must take into account the versatility and flexibility of the available options. A much greater degree of variety and diversity exists within the array of remote sensing tools and techniques currently available than is evident within cup anemometry. The standards and guidelines that govern the use of cup anemometry can afford to be more prescriptive about the devices to be used as a result of this relatively lesser degree of diversity.

When developing guidelines and standards for remote sensing devices it is important to avoid imposing a similar level of prescriptiveness as this will result in the exclusion of valid solutions from the scope of the guidance.

### Hierarchical Recommendations

In addition, the most cost-effective use of remote sensing may not be just as a simple surrogate for conventional methods based on cup anemometry. There are occasions where simple analogies between the methods cannot be drawn, such as, for example, when considering flow visualisation methods such as PPI and RHI scans. This should be recognised when developing recommendations and guidelines for remote sensing best practice.

In general, the much more diverse range of remote sensing solutions than are available with regards to conventional mast mounted instruments means best practice must therefore

- focus on results, data, and outcomes, rather than details of methodology, and
- not stifle innovation and flexibility with excessive prescriptiveness based on the limited experience of the authors who may not have been exposed to the full range and capabilities of the available remote sensing solutions.

Traceability of the accuracy of remote sensing devices requires comparison with conventional instruments. With the above considerations in mind, these comparisons must be performed on the basis of the measurements of key wind flow parameters by the remote sensing and
Remote sensing in the wind industry

A key signpost in terms of guidance in the use of remote sensing to acquire measurement of key wind flow parameters of relevance to the wind power industry is the Boulder Protocol [1–5]. This was proposed at the 59th IEA Topical Expert Meeting in Boulder, Colorado in October 2009. This is a framework within which to understand and develop best practice: a set of generic objectives whose achievement the guidelines for the technology used (SoDAR/LiDAR) and instrument specific (user manual) guidelines and recommendations should enable. This framework is illustrated in Figure 4. This framework is set within a hierarchy of inter-related guidance. The framework describing a general approach to conducting the comparison of remote sensing devices with reference instrumentation and their subsequent field deployment is augmented by technology specific guidelines which deal with particular considerations that arise in the context of the category of remote sensing device used, such as SoDAR or LiDAR. These guidelines are ultimately augmented with model specific guidelines, or user manuals.

The framework of the Boulder Protocol requires that

- instrument performance is verified by comparison with a suitable reference,
- the instrument is subsequently operated in the mode in which it has been verified,
- the circumstances in which it is operated are equivalent to those in which verification has been achieved,
- bankability is ensured by deriving annual energy production (AEP) percentiles from the resulting data with reference to a complete, robust and unbiased uncertainty analysis that incorporates all sources of uncertainty, and
- other relevant guidance is followed, in particular the technology and model specific recommendations.


- siting (fixed echoes, complex terrain),
- maintenance,
- calibration/test/audit: documentation, traceability, and
- understanding the data that come from the SoDAR

The Boulder Protocol is adopted in Appendix A of these guidelines. As yet no IEA guidelines for LiDAR have emerged from this process.

Further to the definition of bankability,

- bankability is not the prerogative of a particular product or service provider, and
- bankability is not instrument dependent

Achieving bankability requires two things:

- the level of AEP considered sufficiently reliable on the basis of the uncertainty analysis is adequate for financial purposes, and
- the resource assessment and related uncertainty analysis upon which this level of production has been predicted is robust, complete, and unbiased.

That is, bankability does not require that a specific instrument is used; rather it requires that whatever instrument is used has been operated correctly and that its performance in the circumstances in which it has been operated is adequately well understood. Bankability has clear, open, transparent and specific technical requirements relating to project risk and uncertainty described clearly in terms of Boulder Protocol article 4.1.

A key consequence of the variety of options now available due to the advent and adoption of remote sensing is the need to design, implement and document a proper development methodology for measurement campaigns that considers the requirements, specification and design of the campaign, and relates this in a traceable way to the implementation of the campaign, the analysis of the data and the reporting of the results. Measurement campaigns
were previously much more restricted by the limitations of the instruments available, and to a
certain extent these limitations made the campaigns self-designing: what was possible
determined the campaign design to a greater extent than what was desirable. However, the
range of assessments that remote sensing now makes routinely available places a new
emphasis on considering in detail the precise purpose of a measurement campaign and what its
objectives are. A paradigm shift is underway which requires a greater deal of effort in the initial
stages of measurement campaign design to ensure the greatest benefit is achieved from the
measurements. It is proposed here that a simple “V” design methodology may in the first
instance be adopted, as illustrated in Figure 5. Initially the requirements of the campaign must
be clearly articulated, before the campaign is specified and designed in detail. The
implementation of the campaign results in the acquisition of data which are analysed to deliver
results. The thorough and complete documentation of every stage of this process and the
manner in which it relates to the stages following and preceding it allow the results to be
compared meaningfully to the initial requirements of the campaign.

![Figure 5: remote sensing measurement campaign design methodology](image)

Campaigns were previously designed around what measurements were possible. The
capabilities of remote sensing mean campaigns can now be designed around what is required –
“what do I want to measure?” instead of “what can I measure?” It is only by adopting a rigorous
measurement campaign design and development methodology that we can fulfil the paradigm
shift underway and realise the promised benefits offered by remote sensing.

**Annex L of the 2nd edition of IEC 61400-12-1**
The IEC standard governing the power performance assessment has recently been undergoing
revision, and one of the aims of this revision is to include guidance on the use of remote
sensing devices in power performance assessment of wind turbines. The committee draft of the
2nd edition of IEC 61400-12-1 [7] includes normative guidance for the use of remote sensing in a
new Annex L.

While restricted in scope to power performance tests, important elements of Annex L of this
standard, and the provision and guidance it makes for the use of remote sensing, are more
widely applicable, and are likely to be adopted when using remote sensing in general wind
power applications. Annex L describes, in particular

1. type classification of instrument,
2. unit verification of performance, and
3. confirmation of performance during application

That is,

1. models of remote sensing device operated in a particular mode will be classified in a
manner analogous to the current classification of cup anemometers, based on tests of
the sensitivity of the accuracy of the devices to variations in environmental variables
such as, for example, (and not limited to) precipitation, wind shear and temperature
This type classification will provide an indication of the accuracy of an instance of the model of remote sensing device when operated in the given mode.

2. Individual units of the device are also required to undergo performance verification, in which their measurements are compared to measurements made by reference instruments. This will indicate if the individual unit conforms satisfactorily with its type classification.

3. Finally, when deployed in the field, some confirmation is required to establish that the device is still performing in a manner that complies with its type classification and the results of its performance verification.

This hierarchy of tests is illustrated in Figure 6. Guidance in relation to items 1 and 2 above are more generally applicable. The guidance given in relation to item 3 is application specific and in the case of the Annex L relates only to power performance assessment. Comparable guidance can be developed for other applications.

**Type classification**
- Comparison with mast mounted reference instruments
- Sensitivity of performance to environmental variables tested
- 2 instances of device, 2 test sites, minimum of 3 tests
- Datasets sufficiently long to include variation in environmental variables

**Acceptance criteria**
One key consideration when assessing the suitability of a particular remote sensing device for a particular application is the acceptance criteria arising from that application. This relates to the confirmation of performance during the application. Acceptance criteria are often applied to the results of performance verification.

Examples of acceptance criteria include:
- **analytical criteria** (e.g. NorseWind [8]): Set criteria are applied to parameters derived from the performance verification exercise, such as
  - regression slope,
  - correlation coefficient, and
  - data availability;
- **operational criteria**: the results of the performance verification inform the uncertainty analysis associated with the intended end use. Acceptance relies on a sufficiently
positive impact on uncertainty, possibly assessed in terms of reduction in project uncertainty for a given investment in data acquisition.

One key benefit of remote sensing surveys is the ability to distinguish between losses and uncertainties in more detail. For example, an influence on a wind project under development, such as the impact of a nearby operational array, may have previously been inadequately assessed because of the limitations of instruments and methods prior to the advent of remote sensing. The losses associated with this impact may have been reflected in an uncertainty that was applied to the AEP distribution. Remote sensing methods, in particular 2nd generation flow visualisation techniques that allow detailed wake data to be captured, allow this loss to be assessed. As a result a loss may be applied which lowers the median, or P50, AEP, while at the same time the 10th percentile, or P90, is raised as a result of the reduction in uncertainty resulting from the assessment.

Other good guidance on remote sensing methods and acceptance criteria to assess the suitability and applicability of a particular instrument can be found in [9-11]. Other guidance exists but in some instances, while useful, it is overly specific and its relevance is restricted to certain models with which the authors are familiar.

Conclusion
The rich diversity of solutions requires an approach that is focussed on outcomes, data, and results, rather than the technical details of a narrow range of solutions that are currently popular but may not be representative of the solutions more widely available in this highly varied and rapidly developing field. A focus on outcomes and a resistance to overly prescriptive guidance and recommendations which are more properly the province of the user manual will help future proof the developing regulatory environment for remote sensing, such that the full benefits these technologies offer can be realised rather than inhibited. Overly prescriptive recommendations that provide advice that should be covered in a user manual rather than a broader outline of best practice serves to stifle rather than encourage competition in the development of optimal remote sensing solutions for the wide variety of application areas these techniques are opening up for us, in many instances for the first time. In addition, the limitations of the measurement equipment available prior to the advent of remote sensing should not condition our thinking such that the valuable assessments that are now possible for the first time are overlooked.

The support of a well-established community of experienced and expert practitioners with a detailed literature on the subject is already available.

Remote sensing is changing the way we think about wind energy assessments.

References