Assessment of measurement quality in Laser and Phase-Doppler techniques: an information theory approach

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In Laser- and Phase-Doppler diagnostic techniques, measurements consist of probability distributions of particles dynamic characteristics (velocity in Laser-Doppler and velocity+size in Phase-Doppler). For the experimentalist, while measuring, it is important to know if the information acquired is enough and reliable for further statistical analysis of the flow. Therefore, this work consists in devising a method, based on information theory, to assess the measurement quality and provide stopping criteria to the experimentalist for ending a measurement. Usually, the approach to do that depends on distribution moments. Namely, when the error of these latter is sufficiently low, the experimentalist is ensured about the reliability and quality of a measurement. However, in a way, data reliability becomes dependent on the distribution moments, rather than the distribution itself, while the measurement is actually the distribution and not its moments. The method proposed overcomes this limitation evaluating if a stabilized probability distribution has been reached or not, thus, enabling a real-time assessment of measurement quality prior to any statistical analysis.

In information theory, the concept developed by Shannon of information entropy \( H(p) \) has all the typical characteristics of a measurement uncertainty quantity (maximum for uniform distribution; small change in probabilities induces small change in \( H(p) \); it is a function of the distribution itself):

\[
H(p) = - \sum_{k=1}^{N_{bins}} p_k \ln(p_k)
\]

where \( p_k \) is the probability associated with class \( k \). Moreover, the fact that \( H(p) \) depends on the distribution, when this changes, the information entropy will change accordingly giving the experimentalist a better perception of its evolution during a measurement. Previous research on the application of information entropy to the real-time assessment of measurement uncertainty in spray characterization has shown that \( H(p) \) tends to stabilize with an increase of the number of samples, meaning that the information-entropy rate tends to zero. However, in interpretative terms, it is difficult to understand what that stabilization actually means, except that, as an uncertainty measure, it is stabilizing for a certain distribution. Therefore, the “excess entropy” concept (\( EE \)) is used instead. In this work, \( EE \) is equivalent to the normalized information entropy (\( EE = H(p)/\log(N_{bins}) \)). The “excess entropy”, \( EE \), quantifies how much information must be gained before it is possible to infer if a given data set is providing all the information the experimentalist needs to accurately characterize the flow. When \( EE \) stabilizes, it means we are not gaining more information by acquiring more data for longer measurement periods. Thus, a stabilization criterion is defined and applied in two case-studies with Laser-Doppler Anemometer and Phase-Doppler Interferometer measurements. The application of the Information Theory method (IT method) devised evidenced that: i) a statistical analysis considering a number of samples sorted with the IT method devised significantly similar results to the statistical analysis using the entire sample size; ii) the IT method is able to capture changes in probability distributions while measuring; the measurement time is substantially reduced, while maintaining its accuracy, thus, improving measurement efficiency.

![Illustration of the verification scheme for the stabilization of EE.](image)

![Measurement efficiency in the LDA experimental evidence provided in Barata et al. (2008) and Silva et al. (2008) using the IT method.](image)

References