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Machine learning approach for fast evaluation of filtered Rayleigh scattering measurement data

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Abstract

A main issue of data processing of filtered Rayleigh scattering (FRS) measurements is the correct numerical description of the Rayleigh scattering profile. Commonly used physics-based models, such as the Tenti S6 and the Pan S7, although proved to be exact, are computationally very time-consuming. In space-resolved FRS measurements, processing of data collected by hundreds of thousands of camera pixels, becomes a significant computational task. Analytical approximations of the established numerical models could overcome that drawback. However existing analytical approximations are not stable enough or do not adequately describe the Rayleigh scattering profile in wider gas flow regimes.

In order to accelerate FRS data processing, we have resorted in the current project to machine learning (ML) approach, a powerful computational technique, which becomes nowadays an efficient and wide-spread working tool, due to highly developed algorithms and a range of available software. ML performs fast approximations of the established models of the Rayleigh scattering profile on the basis of numerical regularities of data, without any knowledge of the physics behind the data. To create ML prediction functions, one needs to perform a teaching procedure, which relates input model parameters with a set of output profiles, the so-called training set. In our case, it is a set of Rayleigh scattering profiles or a collection of FRS intensity spectra, corresponding to all parameter variations expected in forthcoming measurements. These curves can be either generated numerically with one of the established models or obtained directly from an experiment. All preparative calculations, including generation of the training set and the teaching procedure, can be done in the order of minutes. The striking advantage of the ML approach is that the predictive function can be recalculated very fast for another model, input parameter set or parameter range.

While replacing the commonly used Tenti S6 model with ML generated Rayleigh lineshape leads to a reduction of the processing time of about 10 times, application of the ML approximation directly to FRS intensity spectra has provided a 200-fold decrease of required computational time in comparison to conventional methods. It comes together with a fairly good accuracy. Estimated pressure, temperature and velocity, obtained with help of ML from gas flow FRS measurements, differ from the results achieved with the Tenti model not more than 5 hPa, 0.5 K and 2 m/s correspondingly. Further improvements are in progress and will be discussed together with the application of an experimentally calibrated ML approach for calculating the Rayleigh scattering profile.

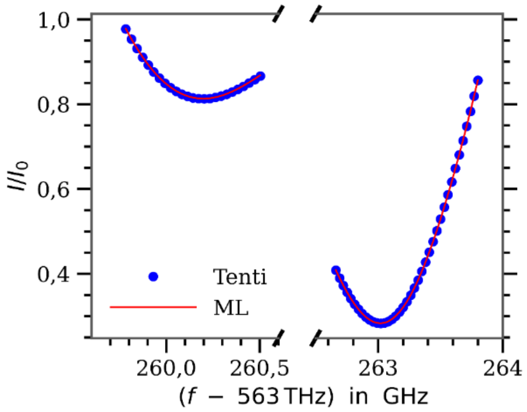

Fig. 1: Quality of FRS spectrum approximation.