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Qlunc: A Python package for quantification of lidar uncertainty

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Software

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Summary

Qlunc, for Quantification of lidar uncertainty, is an open-source, freely available (https://github.com/SWE-UniStuttgart/Qlunc) python-based tool that aims to estimate the uncertainty of a wind lidar device, including hardware and data processing methods. Based on the OpenLidar architecture (Clifton et al., 2019), it contains models of the uncertainty contributed by individual lidar components and modules, that are then combined to estimate the total uncertainty of the lidar device.

The code is meant to be as modular as possible, easily allowing lidar components' (represented by python objects) interchangeability and outcomes' repeatability (see Figure 1). Furthermore, it allows to easily integrate different uncertainty methods or interface external codes. Qlunc has an objected-oriented structure taking advantage of python features; by using python objects and simulating real lidar components, the code puts all together in modules and, eventually builds up a lidar digital twin. This, combined with the underlying open-source code attribute, defines an attractive scenario for sharing knowledge about lidar uncertainties estimation methods. It also encourages collaborations among wind lidar key experts aiming to characterize a common lidar architecture for different types of lidars, to assess wind lidar data processing methods or even helps to get a consensus for lidar terminology, giving place to a lidar ontology, which is a developing project driven by Andy Clifton, Nikola Vasiljevic and Francisco Costa (Vasiljevic et al., 2021; Vasiljevic & Clifton, 2021).

The source code for Qlunc has been archived to Zenodo with the linked DOI: (Costa, 2021)

Motivation

Measuring uncertainty means doubt about the validity of the result of a measurement (Metrology, 2008) or, in other words, it represents the dispersion of the values attributed to a measurand. The importance of knowing uncertainty in measurements lies both, on the quality of the measurement as on the understanding of the results, and it can have a huge impact on the veracity of an experiment or measuring set up. In this sense, wind lidar measurement uncertainties assessment plays a crucial role, since it can determine decision-making processes and therefore the global performance of a wind facility.

The scope of this project is to create an open, standardize and collaborative reference numerical framework to describe unique lidar architectures, characterize lidar uncertainties and provide the needed tools for others to contribute within this framework. This is so, but following lines of OpenScience Principles (Bezjak et al., 2018), the underlying main motivation of this project is to create open and sharable tools and knowledge to reinforce or promote new or

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existing links and to foster collaborations among research institutions and/or industry, within the wind energy community, but not limited to it.

`Qlunc` available capabilities

Currently, `Qlunc` can perform both, VAD and scanning lidar patterns. For now, it can perform lidar hardware uncertainties from photonics module, including photodetector (with or without trans-impedance amplifier) and optical amplifier components, as well as optics module uncertainty including scanner pointing accuracy distance errors and optical circulator uncertainties. In the near future, uncertainties regarding other hardware components and data processing methods will be impemented in the model.

Output plots show different signal noise contributors of the photodetector components and estimates of scanning points distance uncertainty.

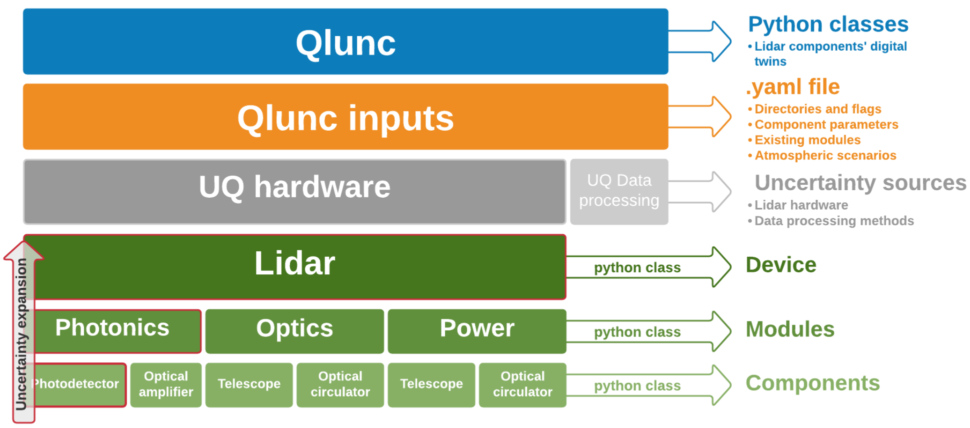

Figure 1: Qlunc basic structure.

Usage

Creating a lidar digital twin

Each component, pertaining to the correspondent module (e.g. photodetector belongs to the photonics module) is created as a python object and enclosed in other python class, which represents the aforementioned module. Following this procedure these lidar modules are, in turn, included in the lidar python class, which gathers all classes corresponding to the different modules a lidar is made of, thus creating the lidar digital twin. Dot notation methodology is used to ask for lidar component properties and uncetainties as well.

Uncertainty estimation model

All components are characterized by their technical parameters and their uncertainty functions, which are feed to the code via a yaml file. Combined uncertainties throughout components and modules are computed according to the Guide to the expression of Uncertainty in Measurement (Metrology, 2008) (GUM) model.

As mentioned above, the code claims flexibility and aims to foster collaboration, especially among researchers. To encourage both, flexibility and further collaborations each lidar module has its own uncertainty estimation function, which includes the components the module is made of. These stand-alone uncertainty estimation functions are easily exchangeable, just in case users want to use another uncertainty model.

Working example and Tutorials: Do it yourself

Included in the `Qlunc` repository users can find Jupyter Notebooks-based tutorials (https://github.com/SWE-UniStuttgart/Qlunc/tree/Qlunc-V0.9/Tutorials) on how `Qlunc` works, providing a tool to help them get started with the software. Tutorials' Binder badge is also provided to ease accessibility and reproducibility. Users can find more info about these tutorials in the readme file attached to the Qlunc repository. Apart from the tutorials, the package includes a functional working example. More information about this working example is given in the readme, included in the `Qlunc` repository, where the process of creating a lidar digital twin is treated in depth.

Future development roadmap

Over the next year, we plan to implement further lidar hardware modules in the model and compute their combined uncertainties. Most significant data Processing methods, which are expected to be the highest uncertainty contributors, will be assessed and implemented in the model during the next project stage, as well.

`Qlunc` is a modular numerical framework, aiming to combine with other lidar codes dealing with lidar uncertaintes. In this sense, `Qlunc` in combination with other existing tools like yaddum (Vasiljevic & Courtney, 2019) and mocalum (Vasiljevic, 2020) will help to improve lidar uncertainty estimations, thus increasing lidar measurements reliability. The "openness" of these group of tools makes it possible to share within the wind energy community and even beyond it.

One of the next objectives is to align the lidar components/parameters/characteristics labeling process, used by Qlunc, to the controlled vocabulary resulting from an ongoing collaboration regarding a lidar ontology within an IEA Wind Task32 initiative, aiming to achieve a standard for lidar components labeling.

All documentation from the project, scientific articles derived from the research period, tutorials and raw code as well are meant to be provided throughout a sphinx-based online site, to give possible users all needed information to dive into the numerical framework and get used to the Qlunc routine.

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