**Q**uantification of **l**idar (hardware) **unc**ertainty

**Qlunc**

Tags: wind lidar, lidar hardware uncertainty, OpenScience, OpenLidar

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Introduction

Qlunc, for **Q**uantification of **l**idar **unc**ertainty, is an open-source, freely available (link to the repository) 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 [1], 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. 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 lidar field experts aiming to characterize a common lidar architecture for different types of lidars, to assess 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 Nikola and others in [reference].

# Motivation

Measuring uncertainty means doubt about the validity of the result of a measurement [2] or, in other words, it represents the dispersion of the values attributed to a measurand. The importance of knowing uncertainty in measurements lies on both, the quality of the measurement and understanding of the results, and it can have a huge impact on the veracity of an experiment or measuring set up, hence in decision-making processes based on the outcomes.

The scope of this project is to create an open, common and collaborative reference numerical framework to describe unique lidar architectures, characterize lidar uncertainties and provide a tool for others to contribute within those frameworks. This is so, but following lines of OpenScience Principles, the underlying main motivation of this project is to create or reinforce existing links within the wind energy community, to create open and sharable knowledge and to foster collaborations among research institutions and/or industry again, within the wind energy community, but not limited to it.

# Qlunc available capabilities

At this stage, hardware uncertainties coming from specific lidar modules, namely photonics and optics, are under assessment.

Currently, Qlunc can perform VAD and scanning lidar patterns and it can calculate uncertainties from photonics module, including photodetector (with or without trans-impedance amplifier) and optical amplifier uncertainties, as well as optics module uncertainty including scanner pointing accuracy distance errors and optical circulator uncertainties. For each module, the Guide to the Expression of Uncertainty in Measurement ([GUM](https://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf)) [2] is applied to calculate uncertainty expansion through all components and modules.

Plots can show different signal noise contributors in the photodetector components and scanning points including their distance uncertainty.

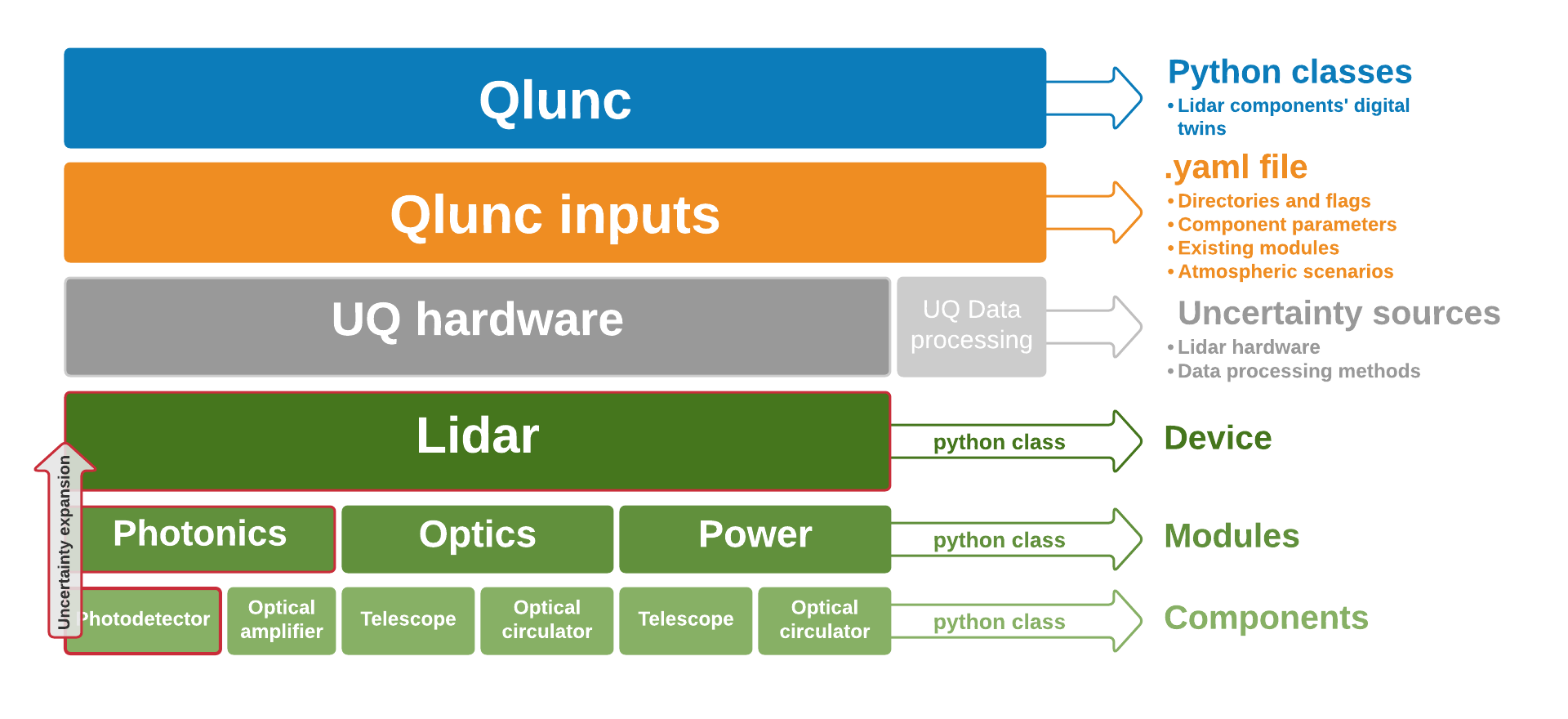


Figure 1. Qlunc basic structure

# How is Qlunc working?

## 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.

## 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. Uncertainties are computed according to the Guide to the expression of Uncertainty in Measurement ([GUM](https://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf)) 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

User can find tutorials on how to begin using Qlunc by downloading the Qlunc repository from <https://github.com/SWE-UniStuttgart/ViConDAR.git> (once it is public you have access).

Apart from the tutorials, the package includes a functional working example. More information about this working example is given in the readme attached to the corresponding folder (`TestFiles\_Qlunc`) included in the Qlunc repository, where the process of creating a lidar digital twin is treated in depth.

# Results

* Dot notation. How to get lidar parameters?
* Asking for uncertainties and code modularity.
* Plots
* tutorials

# Conclusions

Putting all above information together Qlunc will serve to increase confidence in lidar measurements by fostering collaboration among experts and institutions. Despite Qlunc is yet neither tested nor validated with actual data it promises to be a useful tool to assess lidar uncertainties. The possibility of analyzing noise contributors before a lidar is built can give relevant information about which noise terms we should account for, depending on the input power interval we are working with. This can save effort, design time, and allow us to, maybe, create specific components for specific sites, e.g. on/off-shore, or measuring tasks. For now, is not a full-featured application, since many components, modules and new uncertainty sources must still be applied, but offers a main structure where user can see main components, features and capabilities of a lidar measuring device.

Lidar hardware uncertainty is not relevant for lidar uncertainty assessment in comparison with uncertainties introduced by lidar data processing methods.

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# References

{Bibliography}

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