Ph.D. Exchange at DTU Wind Energy; Risø Campus, Denmark – Spinner LiDAR

Feedback report for IPID4all

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Host: Prof. Torben Mikkelsen
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Topic: Spinner-based LiDAR technology for inflow measurements of wind turbines

Introduction

I have been working as a scientific researcher and Ph.D. candidate in the Wind Energy Systems (WESys) research group of ForWind-Oldenburg, led by Prof. Dr. Martin Kühn, since October 2014. My project is focused on light detection and ranging (LiDAR) applied in the field of wind energy. With LiDAR technology, wind speeds can be measured remotely at different points in space by determining the Doppler shift between an emitted and backscattered laser beam signal. The Technical University of Denmark (DTU) developed a short range, continuous wave Spinner LiDAR (see Fig 1.), which operates either from inside the spinner or on top of the nacelle of a wind turbine in order to evaluate two-dimensional inflow wind fields on a plane at a distance of 10-150 m from the rotor plane.

Fig. 1: Spinner LiDAR mounted on the nacelle of the CART 3 turbine at NREL, Colorado (source: DTU and NREL)

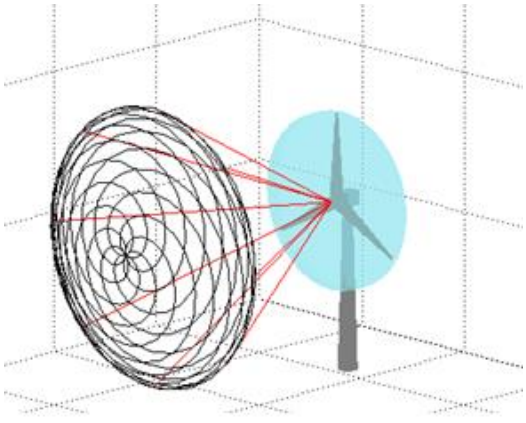

Fig. 2: Spinner LiDAR 'rosette' scan trajectory from a system mounted in a wind turbine hub

The scanner has a high sampling rate of 400 Hz, enhancing the measurement of turbulence effects in the inflow or the near wake of a wind turbine. Because the LiDAR system is set up with two prisms that rotate continuously with a fixed speed ratio of 7/13, the characteristic resulting 'rosette' scan pattern covers a spatially highly resolved part of a cone with a base angle of 30° (see Fig. 2). Each of the full 2D wind scans are acquired every second, meaning that there are 400 measurement points per scan.

DTU is currently constructing a Spinner LiDAR for ForWind in the scope of an ongoing collaboration in the WindScanner.eu project. During my Ph.D.

research I will be working with this device, so it was very helpful that the exchange of two separate five week periods at DTU allowed me to get acquainted with the LiDAR hardware and software and get hands-on experience with its measurement data. In this short report on the exchange, I will discuss the preliminary analysis of LiDAR measurements, the collaborative research on wind field reconstrucion that was initiated and my personal social experience of the exchange. After that, I will explain my further plans for collaboration with DTU Wind Energy.

First measurement data analysis

During the exchange period, DTU Wind Energy has been involved in a measurement campaign as part of the ongoing INNWIND.EU project together with NREL, Colorado. The main goal is to develop a wind turbine feed-forward contol algorithm that is driven solely by wind speed data measured by the LiDAR ahead of the wind turbine. While at DTU, I was one of the first persons who started analysing the measured data. This way, I could develop a good feeling on how to handle data and what challenges are involved with the measurement campaign. For example, one of the problems was wind turbine blade interference, since the LiDAR was mounted on the nacelle instead of - as intented - in the tip of the rotating spinner of the CART 3 turbine at NREL, causing invalid data everytime when a blade passes the field of sight of the LiDAR. Properly filtering these data points is a necessary pre-processing step. Also other outliers, some with unknown error sources, are filtered out before using the data. Figure 3 shows an example 3 s wind field scan of the line-of-sight velocity measured by the LiDAR. After the data pre-processing, approximatly half of the theoretical 1200 measurement points are left and these are represented by black circles. The wind field is interpolated in between the measurements and illustrated with a color plot. Notice that the highest wind speeds are found around the center of the plot. In case of a homogeneous wind field with a wind direction perpendicular to the rotor plane, this is directly related to the LiDAR scanning angles. Since the measured quantity is in fact the projection of the 3D wind velocity vector on the line-of-sight of the LiDAR laser beam, the larger scanning angles at the boundaries of the scanned area yield smaller wind speed components.

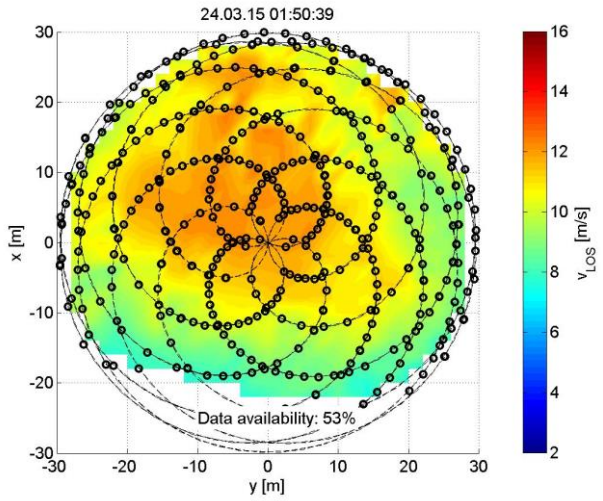

Fig. 3: Example of a 3 s wind field scan with the Spinner LiDAR (source: DTU and NREL)

Wind field reconstruction

A common issue that needs to be dealt with is that a single LiDAR can only measure the wind speed component that corresponds to the the line-of-sight projected wind velocity (a 3D vector) along the direction of the laser beam. In the literature, this is sometimes referred to as 'the cyclops dilemma'. In wind energy research, therefore, it is generally required to identify multiple components of the wind speed. The ultimate goal is to measure all three wind components of the three-dimensional wind speed vectors from LiDAR measurements. One of the pragmatic solutions is to scan with three different LiDAR units with different scanning angles, such that a linear system with three equations and three unknowns is established (see Fig. 4). Another method is to combine information from the measurements with a known physical model description. The latter structure is used by me to formulate a feasible methodology with which a 3D wind field reconstruction from a single scanning Spinner LiDAR will result. This is currently being investigated in collaboration with DTU Wind Energy.

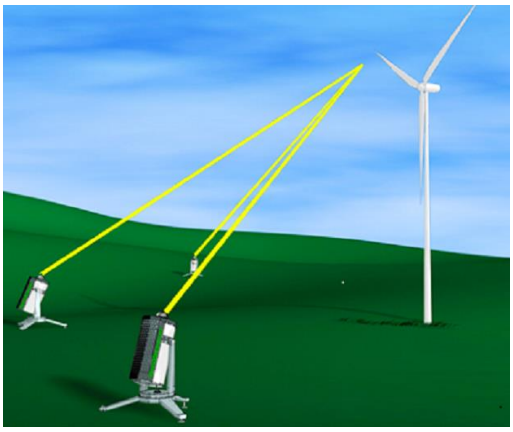

Fig. 4: 3D WindScanner LiDAR setup (source: WindScanner.eu)

In particular, a Kalman Filter will be established to find a best suitable solution for a wind vector based on an atmospheric flow prediction model and measured data. The structure of the Kalman Filter makes it possible to use LiDAR measurements that do not coincide with the grid on which the flow model operates. During the exchange, I started working on the framework of this methodology and together with the DTU Wind Energy colleagues Prof. Torben Mikkelsen and Dr. Poul Astrup a research plan was made. Because the scope of this research topic is large, it will extend beyond the short exchange and therefore we will keep working together on this from this point. When in the end a successful algorithm is developed, a publication will be aimed for.

Personal experience

As a Dutch person, it should be mentioned that there is no significant difference in working cultures between research institutes in the Netherlands, Germany and Denmark and neither in their cultures in general. However, as a foreign student it is always a challenge to meet friends when staying abroad. As a matter of fact, in my experience most of the people I was hanging out with were also international students. Quite unexpectedly, the majority of the researchers and students working at DTU Risø are not Danish, but from all over the world, including a significant amount of South-Europeans. Most of the foreign colleagues agree on the fact that it is hard to make close Danish friends, with the difficult language being one of the barriers. Although Danish is similar to Dutch and German in terms of grammar and structure, the pronounciation makes it difficult to understand people and also to speak fluently. Luckily, most Danes speak English perfectly and are kind and confident enough to use it. Furthermore, there was a very informal and pleasant atmosphere in the research institute. Overall, it has been rewarding to be working with an interesting group of Danish and foreign people in the DTU Wind Energy Department located at DTU Risø Campus.

Conclusions

I had a successful exchange period in the WindScanner Research and Innovation team at DTU Wind Energy, Risø Campus. I achieved the primary goals of getting acquainted with the hardware and software of the Spinner LiDAR and was able to work with its measurement data and identified the steps needed to be taken to process it to produce useful data sets. This will make it easier to get started once the ordered LiDAR is delivered to ForWind and will help me with my Ph.D. research. On top of these practical aspects, we were able to establish a research plan for an interesting methodology for wind field reconstruction based particularly on the Spinner LiDAR measurements. On a personal level, I strenghtened the relationship with DTU Wind Energy and got to know many friendly and intelligent people, who helped me to find my way in Denmark, inspired me scientifically and contributed positively to my overall social experience.

Outlook

As mentioned before, a research plan was established and this implies that I will keep close contact with the researchers at DTU to progress with our ideas. This research can lead to either a conference poster or presentation, and most preferably also a journal paper. DTU Wind Energy will be involved in research projects related to my Ph.D. topic in the future, where the collaboration with Prof. Torben Mikkelsen will be maintained.

The exchange strenghtened the relationship between ForWind-Oldenburg and DTU Wind Energy and my experience could be the first of several exchanges of students in both ways. Especially considering that these institutes are leading in the field of LiDAR technology and measurements, both with their own contributions, large benefits of the combined knowledge could be gained in different collaboration projects. The IPID4all organisation provides a convenient programme that makes it possible to plan future Ph.D. exchanges, both incoming and outgoing.

Acknowledgments

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I would like to express my personal gratitude to Torben Mikkelsen, Nikolas Angelou and Mikeal Sjöholm from the WindScanner Research and Innovation team, for hosting me during my stay at DTU Risø and supporting me with the research. Also my collaboration with the experienced scientist Dr. Poul Astrup is much acknowledged.

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