Pitch and Roll Angle Calibration for Scanning LiDARs to Reduce Uncertainties in Measurement Height

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Abstract

The application of scanning LiDARs for the measurement of wind speed is a relatively new technology in the wind energy sector and also has potential relevance for various topics,(e.g. measuring the wind speed for power performance test for offshore wind turbines). Scanning LiDARs offer a customizable scanning geometry and are, therefore, able to measure wind speed and wind direction at a position that is not centered on its own position. For such situations, the knowledge of the elevation angle is crucial, as it directly influences the measurement height. For instance, for power performance tests of offshore wind turbines of typical size, an accuracy higher than 0.1° is necessary. Independent from the displayed elevation angle of the device, the inclination of the device must be known.

Objectives

Two built-in electronic inclinometers measure its own orientation within the earth's gravitational field during operation.

In order to achieve a high accuracy of these measurands, these sensors must be calibrated prior to the measurement. A calibration procedure, including detailed uncertainty assessment, has been developed in the testing laboratory of Deutsche WindGuard.

Measurement Setup

To assess the accuracy of the pitch and roll inclinometers of the LiDAR, the elevation angle α of the laser beam in a given configuration of the instrument is compared to the output of the inclinometer. Figure 1 and Figure 2 show schematic overviews of the measurement configuration. Figure 3 shows a photograph of the setup.

The elevation angle α can be measured by two independent methods:

- Direct measurement of the angle α with a theodolite (Method A)
- Indirect measurement of the angle α with the relation $\tan \alpha = h/L$, with h being the vertical displacement of the laser beam at a horizontal distance L from the exit lens (Method B)

Both measurements are applied during the calibration.

Common to both methods is the challenge of finding the invisible laser beam [1]. The wavelength of the laser is approximately 1550 nm, i.e. the laser emits in the infrared. Therefore direct detection of the outgoing laser was not feasible.

The location of the laser beam was identified by iteratively blocking and unblocking the laser beam with the wooden construction shown in Figure 3.

Blockage of the laser beam occurs when the LiDAR's carrier-to-noise ratio (CNR) decreases significantly for the range gate in approximately the distance of the screen and range gates behind. The CNR is monitored in real-time with a laptop connected to the instrument.

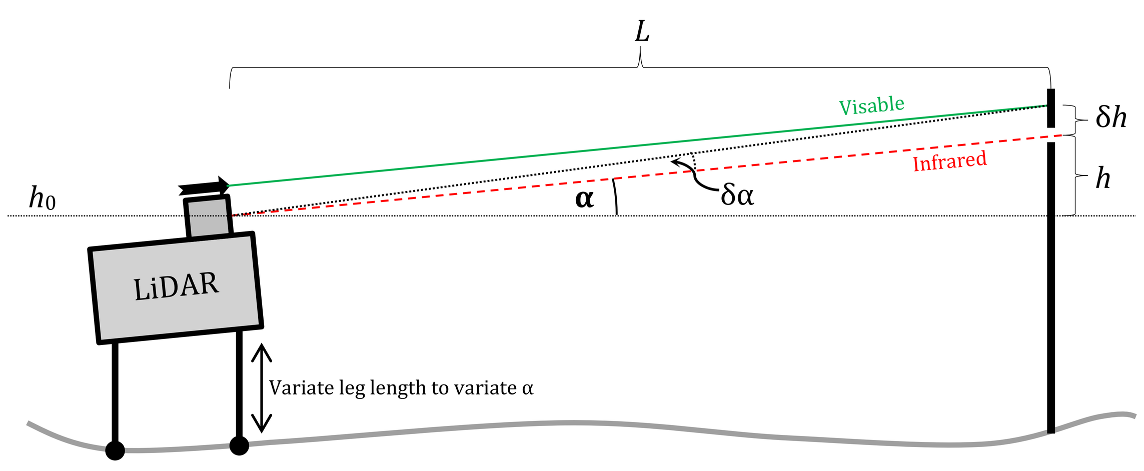

Figure 1: Schematic side view of the measurement setup. Calibration target is the pitch angle α. The infrared laser (red dashed line) can be detected with the gap in the screen at distance L of the LiDAR. The visible laser (green solid line) is approximately parallel to the infrared laser, i.e. the angle δα and the offset δh are fixed during the measurements. The dotted black line is the view direction of the theodolite to the visible laser on the screen. The reference height h_0 is defined by the exit point of the laser beam at the centre of the lens.

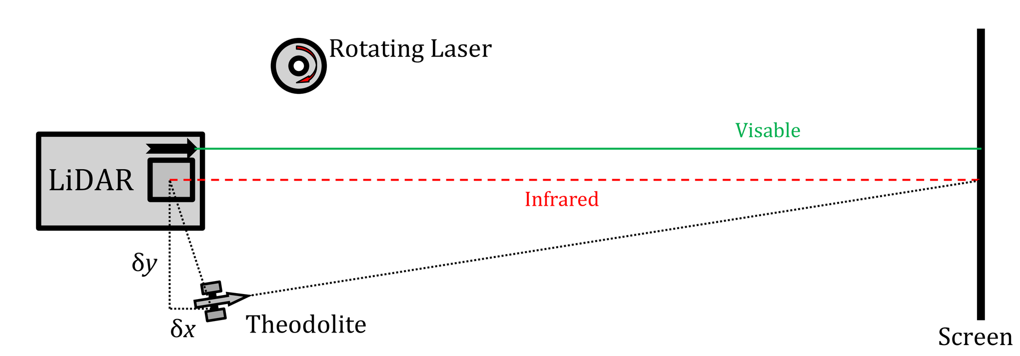

Figure 2: Top view of measurement setup. The rotating laser transfers the reference height h0 from the LiDAR to the theodolite (Method A) and the screen (Method B)

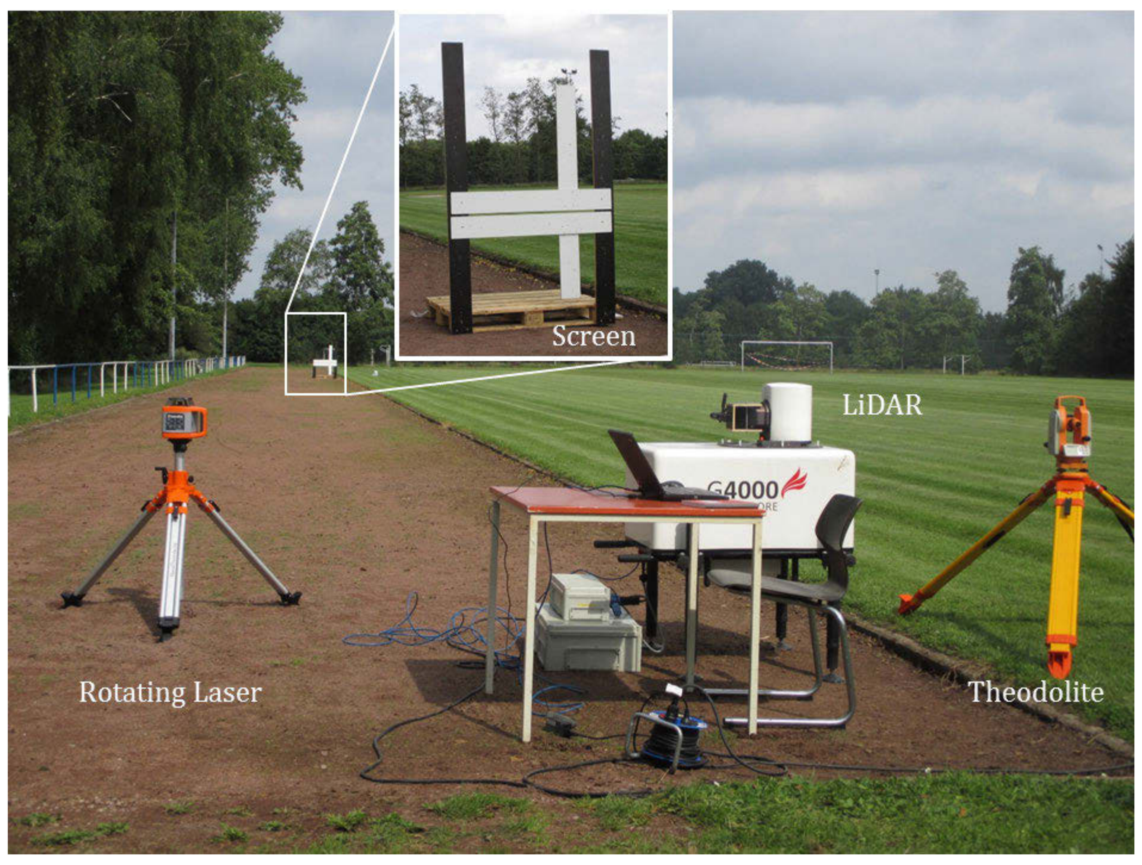

Figure 3: Picture of the experimental setup. The inset shows the screen. It is constructed to identify the location of the infrared laser beam of the LiDAR. The white panels are moved up to the point at which they just do not block the laser. The rotating laser defines a reference height across the measurement site

In order to work out calibration factors in terms of slope and offset, both methods were applied for up to six different inclination angles which are varied by adjusting the legs of the device. Procedure was conducted for pitch and roll angle by rotating the device by 90°.

Results

At this stage, calibration of four scanning Lidars has been performed in the facilities of Deutsche Wind Guard. It turned out, that the inclinometers are more influenced by an offset than the slope factor. Results of all calibrations are listed in Table 1.

Device	Pitch Angle		Roll Angle	
	Slope	Offset	Slope	Offset
	[-]	[°]	[-]	[°]
Device 1	0.98	-0.13	-0.97	0.18
Device 2	1.02	-0.39	-0.99	0.03
Device 3	0.98	-0.07	-1.00	0.27
Device 4	1.03	-0.30	-0.99	0.05

Table 1: Results of calibrations performed at Deutsche WindGuard thus far, Method A applied. Applying Method B is resulting in very similar correction factors.

Detailed calibration results are shown for the pitch angle of device no. 2.

Parameter	Value
Measured Inclination as given by LiDAR	Pitch
Scanning Direction	
Azimuth Angle [°]	0
Zenith Angle [°]	90
Transversal Inclination	
Name	Roll
Displayed Value [°]	0.000
L Distance LiDAR - Screen [m]	83.85
Date of Calibration	2015-07-03

Table 2: Measurement configuration of the pitch calibration

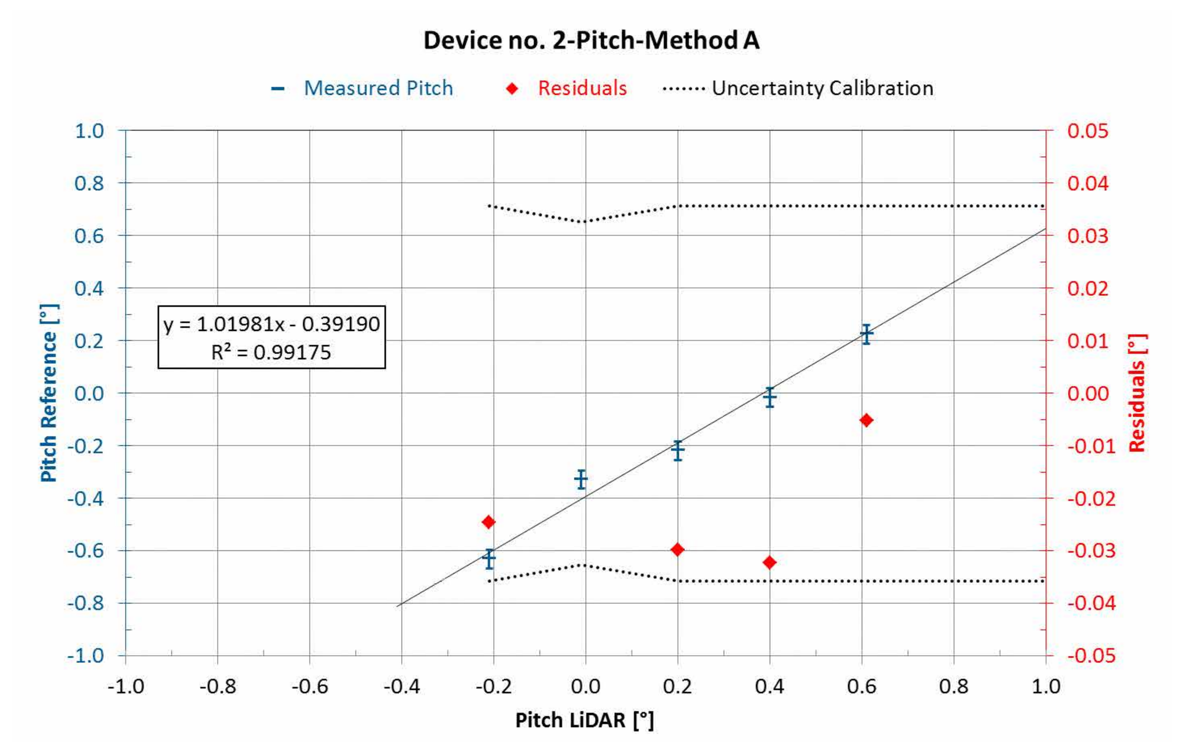

Figure 4: Calibration results of the pitch angle of the LiDAR. The reference inclination was measured by Method A, i.e. direct angle measurements with a theodolite. The blue markers are the reference pitch as function of the pitch given by the LiDAR. The error bars denote the standard uncertainty in pitch. The red diamonds give the residuals, i.e. the deviation between the shown calibration line and the measured values. The dotted lines denote the standard uncertainty of the calibration on the axis of the residuals

Conclusions

A new method of calibrating pitch and roll angle for scanning LiDARs has been developed. The challenge of identifying the invisible laser beam is avoided by the application of an adjustable visible laser beam. Redundant measurement principles verify the reliability of the results.

The results of devices tested thus far lead to the assumption that calibration of the built-in inclinometers is recommended, in order to achieve a high accuracy in elevation angle and consequently in measurement height. For a typical measurement configuration for a power curve test of an offshore wind turbine, a deviation of the elevation angle of 0.1° will result in an error of measurement height of about 0.5 m.

References

1. Calibrating nacelle lidars, *DTU Wind Energy E-0020, January 2013*

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