SOFTWARE TO ASSIST LIDAR ALIGNMENT PROCEDURE BASED ON RAYLEIGH-FIT METHOD

SOFTWARE PARA AJUDAR O PROCEDIMENTO DE ALINHAMENTO DO LIDAR BASEADO NO MÉTODO RAYLEIGH-FIT

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Abstract: Laser-telescope alignment is a key factor in a lidar system, and its setup determines the lidar signal quality. Procedures to accomplish this task may vary depending on the operator, from detailed step-by-step procedures to visual inspection of particular behavior of the lidar signal. No matter the method used, it should be performed by an expertised lidar operator in order to preserve the lidar quality signal. In this work, a software to aim the alignment procedure is presented. With a clear interface, it helps the lidar operator to approach the right alignment state based on a live Rayleigh-Fit applied to the acquired lidar signal. Also, a quantitative result of this alignment is shown, giving to the operator a visual during the alignment procedure. Main features of the tool and working scenarios are presented.

Keywords: Lidar alignment. Lidar acquisition software. Rayleigh-fit.

Resumo: O alinhamento do telescópio laser é um fator chave em um sistema lidar, e sua configuração determina a qualidade do sinal lidar. Os procedimentos para realizar esta tarefa podem variar dependendo do operador, desde procedimentos detalhados passo a passo até a inspeção visual do comportamento específico do sinal lidar. Independentemente do método utilizado, ele deve ser executado por um operador especialista em lidar, a fim de preservar a qualidade do sinal lidar. Este trabalho é apresentado com um software para gerenciar o procedimento de alinhamento. Com uma interface clara, ajuda o operador lidar a aproximar o estado de alinhamento correto com base em um Rayleigh-Fit ao vivo aplicado ao sinal lidar adquirido. Além disso, é mostrado um resultado quantitativo deste reembasamento, proporcionando ao operador uma visão visual durante o procedimento de reembasamento. São apresentadas as principais características das ferramentas e cenários de trabalho.

Palavras-chave: Lidar Alinhamento. Software de aquisição Lidar. Rayleigh se encaixou.

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1 INTRODUCTION

Lidar alignment is a crucial part of the measurement process, and also, a time-consuming task that must be performed by a skilled operator. Depending on opto-mechanical stability of the lidar system, it is very important to have tools to check the alignment state and to find a well alignment scenario in a more easy way. There are different methods to accomplish this task, from inspecting the lidar signal visually, or by applying a well-established method like Telecover (Freudenthaler, 2008) for low ranges and Rayleigh-Fit (Freudenthaler, 2009) (Baars, 2016). In this work, we describe a tool to assist in a lidar alignment process based on the Rayleigh-Fit method. Since the software is tested on a co-axial lidar of the SaverNet Network (SaverNet, 2018), once the far range is aligned, also the short range will be set. In the case of a bi-axial lidar system, the Telecover method should be performed to align lower ranges of the lidar signal.

The software presented in this work applies a real-time Rayleigh-Fit method to each lidar signal acquired, analyzing the goodness of the fit and showing it to the operator in a convenient plot. Having real-time numerical information representing the photons collection efficiency of the lidar optical system makes the decision-making easier in the alignment procedure. Also, it is valuable information to automatize the alignment procedure with ad-hoc hardware.

The software is prepared to work with Licel (Licel) transients recorder systems connected via its network parameters and has available all the settings needed for the right operation.

2 MATERIALS AND METHODS

The core of the tool was developed in Python 3.8.10, being the framework of the graphical user interface (GUI) coded with Flask 2.0.1, HTML/CSS with Bootstrap 4, JavaScript, and jQuerry. The GUI is a web server-based application, accessible with any updated Web browser. This GUI is based on a dashboard, having the general configuration panel on the left side and all the plots in the main panel at the center of the screen. A general view of the software running is shown in Figure 1.

Figure 1 - General view of the dashboard. (1) Settings panel. (2) Range corrected lidar signal (RCLS, green line) and its Rayleigh-Fit (red line). (3) raw lidar signal. (4) alignment-quantification plot, where higher values represent better lidar alignment

In Figure 1, a general view of the dashboard is shown . The control settings are located on the left panel (1), and three plot regions in the main area of the screen. In plot area (2), the range-corrected lidar signal and the fitted pure-molecular lidar signal are shown. The fitting ranges are highlighted in a shadowed pink area, and its limits are set in the setting panel. Plot area (3) shows the raw-lidar signal and in plot area (4) the alignment quantification as a time series value. The settings controls are clustered in sections based on different topics, from hardware to Rayleigh-Fit settings. These sections are:

- **Licel control:** in this section, basic Licel settings are set, like the channel used and acquisition time for the acquisition. Also, basic signal corrections like laser bin offset and bias range. Buttons for start, stop, and save the acquisition are located in this section.
- **Plot Controls:** Maximum and minimum axis settings of the plots. These controls will modify the range axis of the lidar plots of the panels (2) and (3).

- **Rayleigh-Fit controls:** Here, the Rayleigh-Fit ranges are set, together with the ground-based measurements for temperature, pressure, and altitude of the site. This information is needed to correct the temperature and pressure profiles from the radiosounding or model across the day.
- **Sounding controls:** Settings to obtain the temperature and pressure profiles: US standard model or radiosounding. If the latter case is selected, the software will automatically download the radiosonde from the Wyoming web server (https://weather.uwyo.edu/upperair/sounding.html). The station code, region, and date of the radiosounding must be included before submitting this request. To obtain this information, a link with the text “Station list (NOAA Airports)” is included, which displays the data needed to fill the station parameters. The temperature and pressure profiles will be downloaded automatically and used to obtain the molecular extinction and backscattering profiles in the Rayleigh-Fit.
- **Load .ini files:** Controls to define the paths to *global_info.ini* and *Acquis.ini* files. These files are defined by Licel and contain the hardware configuration of the Licel, like channel type and where each wavelength is connected (among other data).
- **TCP/IP Controls:** IP and port settings to connect to the Licel.
- **Laser control:** Start and stop laser controls. This control only works for laser Surelite I-30 from Continuum, connected via serial port. This is the laser used in the SaverNet Network where this software was developed.

After filling the settings panel, the **START** button must be pressed to start the acquisition loop. The acquisition procedure is endless until the **STOP** button is pressed. Since the first signal is acquired, the Rayleigh-Fit will be applied to each profile, showing its results in panel 2 (see Figure 1). At this moment, the operator can align the system with the real-time Rayleigh-Fit's visual information, and its alignment in panel 2 is updated at intervals defined by the acquisition time set in the dashboard. If the alignment is improved, higher values will be shown in the plot of panel 4. How the quantification algorithm works is explained in the next section.

The alignment quantification algorithm

In this section, the method of how the software defines the quality of the alignment is described. The alignment quantification uses the same concept for measuring the bin-shift reported in (Freudenthaler, 2018), where this parameter is obtained by the highest cross-correlation between analog and photon-counting signals. We used this same concept by quantifying the Rayleigh-Fit of the elastic-lidar signals in clean air ranges. This process is done in real-time for each lidar signal acquired during the alignment process. By doing this, if the alignment is close to the optimum, cross-correlation will tend to values closer to 1, and bad alignment states will produce lower correlations values. These parameters are plotted in panel 4 (see Figure 1), showing to the operator numerical feedback of the alignment state.

These operations are done using the elastic corrected-raw lidar signal, after performing bias and trigger-delay corrections. The bias correction is achieved by removing the bias contained in the lidar signal produced by the background photons and electronic noise. This correction is accomplished by removing from the raw-lidar signal the mean value of the last bins of the lidar track. The number of bins used for bias correction is configured in the section “Licel Controls” of the setting panel of the dashboard. In the first version of the code presented here, only the elastic lidar signal must be used for the alignment, since no photon-counting-related corrections are made. The elastic channel selection is in the section “Licel Control” at the setting panel. Future releases will contemplate the option of selecting photon-counting channels for the alignment.

By working with corrected-raw lidar signals instead of RCLS, we avoid larger fluctuations in the alignment quantification values, producing a more stable plot, and providing easier feature discrimination when the alignment state is in its optimal state. Although the alignment quantification algorithm uses raw-corrected signals, the plots in panel (2) (Figure 1) of the dashboard show the RCLS for a better visual interpretation.

The cross-correlated formula is the Pearson’s correlation coefficient (ρ), expressed by:

$$\rho = cov\,(P(r), P_{MF}(r)) \,/ \left(\sigma_P * \sigma_{P_{MF}}\right)$$

Where:

- $P(r)$: Background-subtracted and zero-bin corrected raw lidar signal.
- $P_{MF}(r)$: Fitted-pure molecular lidar signals across the limits defined in the “Rayleigh-Fit” controls.

The pure-molecular lidar signal is defined as: $P_{mol}(r) = \beta_{mol}(r) * e^{\int_0^r \alpha_{mol}(r).dr}$. The optical molecular parameters $\alpha_{mol.}(r)$ and $\beta_{mol.}(r)$ are obtained from radiosonde data or molecular model. Finally, $P_{MF}(r) = a_{fit} * P_{mol}(r)$, where a_{fit} is the constant obtained to reduce the root-mean-square between $P_{mol}(r)$ and $P(r)$ across the predefined ranges. It is obtained using the equation:

$$a_{fit} = \frac{\sum_{iFit}^{eFit} \quad P(r) * P_{mol}(r)}{\sum_{iFit}^{eFit} \quad P_{mol}(r)^2}$$

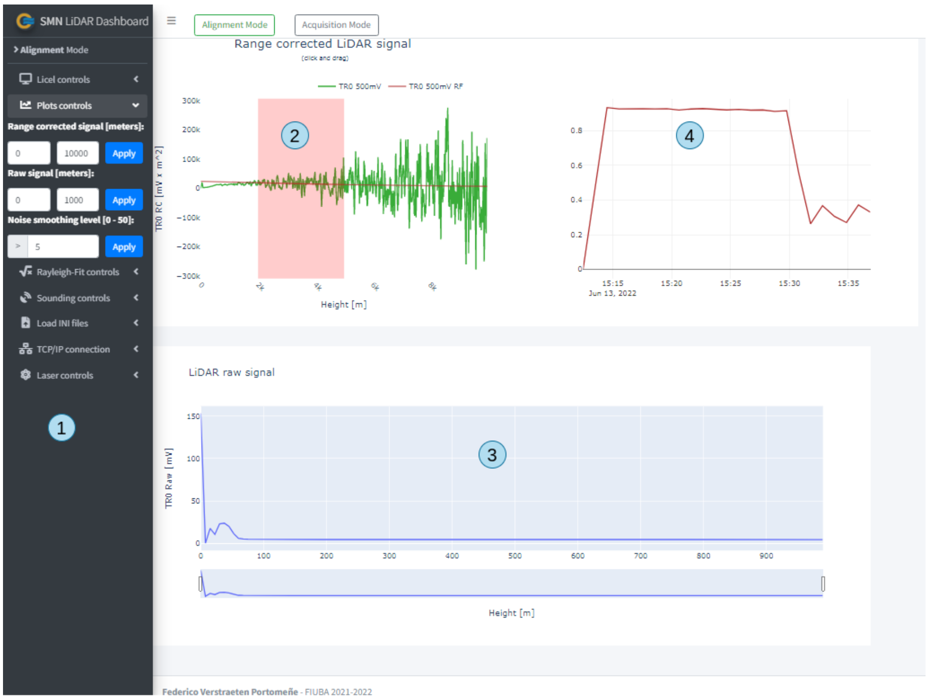
Being $iFit$ ad $eFit$ the initial and end fitting limits of the Rayleigh-Fit, defined in its corresponding section of the dashboard.

3 RESULTS AND DISCUSSION

In this section, the dashboard response during an alignment procedure is shown. This was tested in the Dorrego site of the SaverNet Network, located in the headquarters of the Argentinean Meteorological Weather Service. This lidar system uses an Nd:YAG solid laser type Surelite I-30 from Continuum. A 20 cm diameter and 1 m focal length Newtonian telescope is deployed co-axially to the laser beam. The backscattered photons are filtered in a spectrometric box capable of discriminating de elastic lines emitted by the laser: 355, 532, and 1064 nm. This detection system detects depolarization in the 355 and 532 nm lines.

Figure 2 shows the dashboard during an alignment procedure. The screenshot was taken in a misalignment state (see panels 2, 3 and 4), where the laser was tilted till nearly losing all the signal. Panel 4 shows a time series of the cross-correlation coefficient obtained after each Rayleight-Fit applied to each lidar signal.

Figure 2 - Misaligned RCLS (panel 2) and its Pearson’s coefficient response (panel 4)
The lidar was misaligned on purpose to see how the alignment quantification response



Range corrected signal [meters]: 0 10000

Raw signal [meters]: 0 1000

Noise smoothing level [0 - 50]: 5

Figure 3 shows the dashboard after realigning the lidar from the state shown in Figure 2. Panel 2 and 3 shows a plot of the signal recovered and Panel 4 shows the Pearson coefficient. The latter contains the historic time series of the cross-correlation coefficient. It is interesting to note the rise of the coefficient to higher values after the alignment operations.

Figure 3 - Aligned lidar signal, showing good aligning state in the alignment quantification state plot

Licel parameters:

Ch 1

Sec 60

Bin 10

Bias range [meters]: 22500 30000

In panel 4 of Figure 3 can see the historic time series of the cross-correlation coefficient. Since lidar signals are inherently noisy, and despite the fact that this coefficient is obtained with the corrected-raw signal, it never reaches 1. Since these values depend on the acquisition time, using longer times will produce values closer to 1. The key to take into account here is to maximize this cross-correlation parameter during the alignment by adjusting the relative tilting of the laser-telescope axis or any other opto-mechanical device across the optical path.

The acquisition time used during the alignment procedure should be a compromise between a fast acquisition time, to see the results right the change in the system was made, and long enough to deal with the random noise and produce a smoother cross-correlation plot. An acquisition time of 10 seconds is good enough in the SaverNet lidar used in this work.

The use of Pearson's correlation coefficient shows good performance to quantify the alignment of the lidar signal during the acquisition. Since the fitted pure-molecular profile is practically noiseless versus real lidar signals, it is impossible to achieve a value of 1 in this coefficient, but finding its maximum is a good tracer of the goddess of the alignment. Using raw-lidar instead of range-corrected lidar signals to obtain the cross-correlation improves the plots for a better interpretation, reducing their variations due to the noise and being mostly dependent on the overlap factor.

The software developed brings this tool to anyone who has a Licel as an electronic acquisition system. It is an open-source development, available to anyone who wants to use or contribute to its evolution. It is accessible from the GitHub repository https://github.com/FedeVerstraeten/smnar-lidar-dashboard.

4 CONCLUSIONS

A real-time tool for analyzing the alignment state was developed and presented. The software is able to work in any lidar using a Licel as the electronic acquisition system, being highly configurable for any lidar. The software is capable of being configured in order to modify its parameters in a convenient graphical user interface, from Licel configuration to Rayleigh-Fit parameters. The real time Rayleight-Fit and its goodness using the Pearson's coefficient shows good response to quantify the photon collection state.

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