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SAFETRANS: Unsupervised Visibility Range Estimation Tool, Using 3D LIDAR Backscattering Measurements

***H. X. de Lastic*[1], *A. Papayannis*[1] *and G. Georgoussis*[2]**

(1) Laser Remote Sensing Unit, Physics Department, National Technical University of Athens, Zografou, Greece
(2) Raymetrics S. A., Spartis 32, Athens, Greece
ektorxavie.delastik@upatras.gr

Abstract

The aim of this analysis is to present the meteorological visibility range estimation procedure in the frame of the SAFETRANS project.

The physical infrastructure and software of the system are in active development and fine-tuning with an emphasis on the automation of analysis to the point where deployment and operation can be performed remotely, with minimal supervision, making it suitable to be operated by non-specialist staff.

2. Objectives

The aims of this work should be interpreted within the scope of a system suitable for operational usage by trained, non-researcher staff, along with other instruments providing real-time measurements of atmospheric variables of interest to aviation.

The primary objective of the SAFETRANS project is to provide a functional lidar-based visibility range estimation pipeline that can be integrated in parallel to other equipment.

The second objective is to assess the capability of utilizing scans of the airspace around the lidar system in order to mitigate the effect of simplifying assumptions, such as the horizontal homogeneity of the atmosphere.

The third objective is to provide visibility range estimations over non-traditional lines of sight (LOS) of particular interest that have historically been difficult to readily measure. Examples include slant visibility and visibility at the angle of aircraft approach.

1. Background

Atmospheric visibility is of particular importance for aviation safety, especially in turbid and unstable atmospheric conditions, which play a vital role in airports operation. Facilities related to aviation (i.e. airports) use a variety of instruments to derive estimations of visibility as a proxy for a human operator's ability to clearly identify important landmarks and possible obstacles.

The main approaches to such estimations hinge on measuring the properties of a limited volume of air either contained within the device (nephelometers) or bounded by two or more devices (scatterometers, transmissiometers and cellular networks).

To the extent that the volume of air under scrutiny is situated near an area of interest such as a runway, the results are generalized to serve as a proxy for the local conditions and can, in principle, be calibrated against expert human operators' estimations to derive realistic visibility estimations applicable to human sight.

Application of such methods assumes a largely homogeneous atmosphere in order to generalize results, an assumption violated during intense whether phenomena or in a cloudy atmosphere.

Ceilometers differ from these approaches in that they study a column of air along a specific line of sight, providing an 1-dimensional (1-D) profile of atmospheric conditions instead of the essentially 0-dimensional (0-D) profile of the previous methods. The logical extension of this idea is to use a scanning lidar along numerous different lines of sight in order to provide, with limited assumptions, a 2-dimensional (2-D) profile of the atmosphere along a plane of interest.

This is the base of the SAFETRANS project. We utilize a 3-dimensional scanning lidar system at 355 nm which provides aerosol backscatter profiles both at fixed angles that prove of operational interest and on planes that provide a characterization of atmospheric conditions, allowing traditionally-difficult measurements to be made.

3. Methods

Following data preparation, we provide an unsupervised mode that attempts to supply estimations comparable to a trained researcher's estimation for the distance at which the backscatter return signal descends into noise by exploiting its undifferentiated, stochastic behaviour. Furthermore, we use a simplified method based on the work of Gong et al., 2011 in order to identify any suspect atmospheric anomalies which could render the selection of a point of reference unsuitable for the subsequent signal inversion and analysis.

Having chosen a suitable point of reference, we perform signal inversion along the path of the beam according to Klett, 1981, calculating the extinction coefficient profile along it. In the case of zenith scans at a fixed azimuth angle, we make the simplifying assumption that the extinction coefficient value bounded by two lidar measurements at a fixed altitude change linearly, obtaining a 2-dimensional extinction profile. Thirdly, having obtained a) a set of unrelated measurements such as fixed point measurements or measurements at random angles for calibration, or b) a radially-performed scan at a set elevation angle and varying azimuth or c) a zenith scan at a set azimuth angle and varying elevation, we can use angstrom exponent conversion or empirical models to translate the estimations to the visible part of the spectrum. Lastly, the application of Koschmieder's law (ICAO, 2013) allows the estimation of visibility ranges at any point permissible by the geometry of the extinction coefficient profile generated at the previous step.

4. Results

We present results of the latest iteration of the SAFETRANS system, field-tested at Chania Airport (Greece) from 24/02/2020 to 24/06/2020. In summary, along with field-testing the physical infrastructure of the 3-dimensional lidar system, over 239.000 fixed-point measurements were performed, along with 264 azimuth scans and 148 zenith scans. The scans were performed from 10/04/2020 to 20/04/2020. Figure 1 presents the calculated visibility range around the airport, as can be estimated using an azimuth scan at a fixed elevation angle. At present, this can provide a qualitative measure of visibility, as it provides more flexibility than can be obtained bo other methods, making it difficult to assess and calibrate. In contrast, Figures 2 and 3 use visibility estimates along the runway, provided by the Chania Airport as an external time series against which to compare the estimates of the SAFETRANS system, providing a measure of control for the response of the system to changing atmospheric conditions. Figure 2 directly compares the airport estimates (**red**) to the SAFETRANS estimates along the same line of sight (**black**), after a normalization to eqate their median value in order to facilitate the reader. Figure 3 compares the airport estimates (**green**) to the slant visibility (ICAO, 2013) of an outcoming object at a distance of 5 km and a height of 1 km (**red and black**), showcasing the ability of our system to calculate visibility over arbitrary lines of sight on the plane of a zenith scan. The slant visibility estimate according to the standard ICAO definition, taking into account only the vertical column of air under the object is shown in red. In **black**, we show the results of estimation by calculating visibility vertically and progressively raising the angle until we "lose clear sight" of the ground, as a human observer would do.

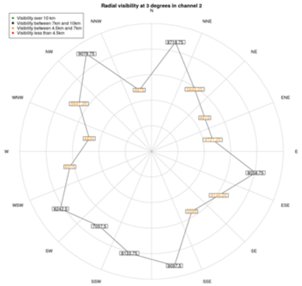

Figure 1. Visibility ranges around the airport, calculated using an azimuth scan.

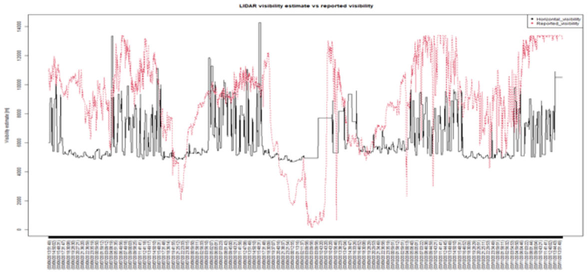

Figure 2. Corresponding behaviour between the horizontal visibility estimates of the SAFETRANS system (black) and visibility estimates by the airport equipment using fixed-point measurements.

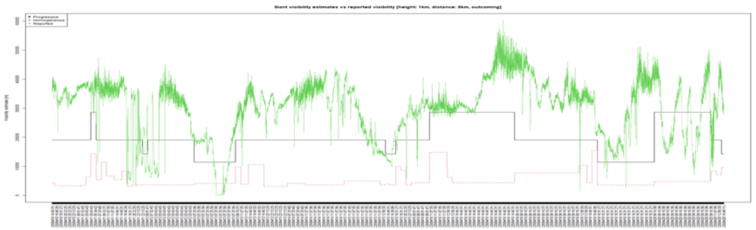

Figure 3. Corresponding behaviour between visibility estimates by:
- airport equipment (green) along the runway
- slant visibility estimates of the SAFETRANS system using the standard ICAO definition (red)
- slant visibility estimates of the SAFETRANS system using a novel approach, mimicking slant visibility estimation by the human eye (red)

5. Conclusions

In this work we presented the rational behind the development of the lidar-based SAFETRANS visibility estimation system, designed to operate alongside other instruments vital to facilities related aviation, in order to provide useful information not obtainable by other conventional techniques. We outlined the two innovations that allow the signal analysis to be automated to the point where non-specialist staff can operate the system and draw meaningful and operationally useful results reliably. We concluded our presentation by showcasing the first results of field-testing the SAFETRANS system deployed at the Chania Airport over a wide span of time and under varying atmospheric conditions. The results show meaningful distributions of visibility estimations and their variation over time corresponds with the more consistent variations of visibility as reported by the airport systems. The sparseness and shortness of the scanning period necessitate further and focused study and verification at the next deployments of the system which will take place during the upcoming field tests to be performed in two other airports in the frame of the SAFETRANS project.

References

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