Detect Non-stationary Stochastic noise in the lidar measurement of atmospheric Co_2 column absorption

Engineering

Mentor: Dr. Paul Racette, Code 555
Microwave instrument technology

Derssie Mebratu, Howard University
Electrical and Computer Engineering

Abstract

Lidar is an active remote sensing instrument built to measure the level of Co_2 concentrations in the atmosphere. In order to accomplish this, lidar emits a laser pulse toward the Co_2 molecule. As a result, light particles (photons) scatter and return to a telescope aligned with the laser. Based on recorded data from light particles as they scatter to and from the affixed telescope, scientists are able to predict and determine the location, distribution, and level of Co_2 concentration in the atmosphere. However, because of stochastic and atmospheric turbulence and background noise in the atmosphere, measurement by lidar of the level of Co_2 concentration in the atmosphere is not ascertainable. In this paper, we introduce both the calibration algorithm and Ensemble Detection Analysis (EDA) methods to identify and understand the uncertainty measurement of Co_2 concentration in the atmosphere by lidar. Also, the behavior of non-stationary stochastic noise within the lidar system is analyzed. The EDS technique allows for the mixing of calibrated noise signals, and the production of ensemble measurements. Review of the collection of ensemble measurements allows us to study and analyze non-stationary stochastic noise in the lidar system.

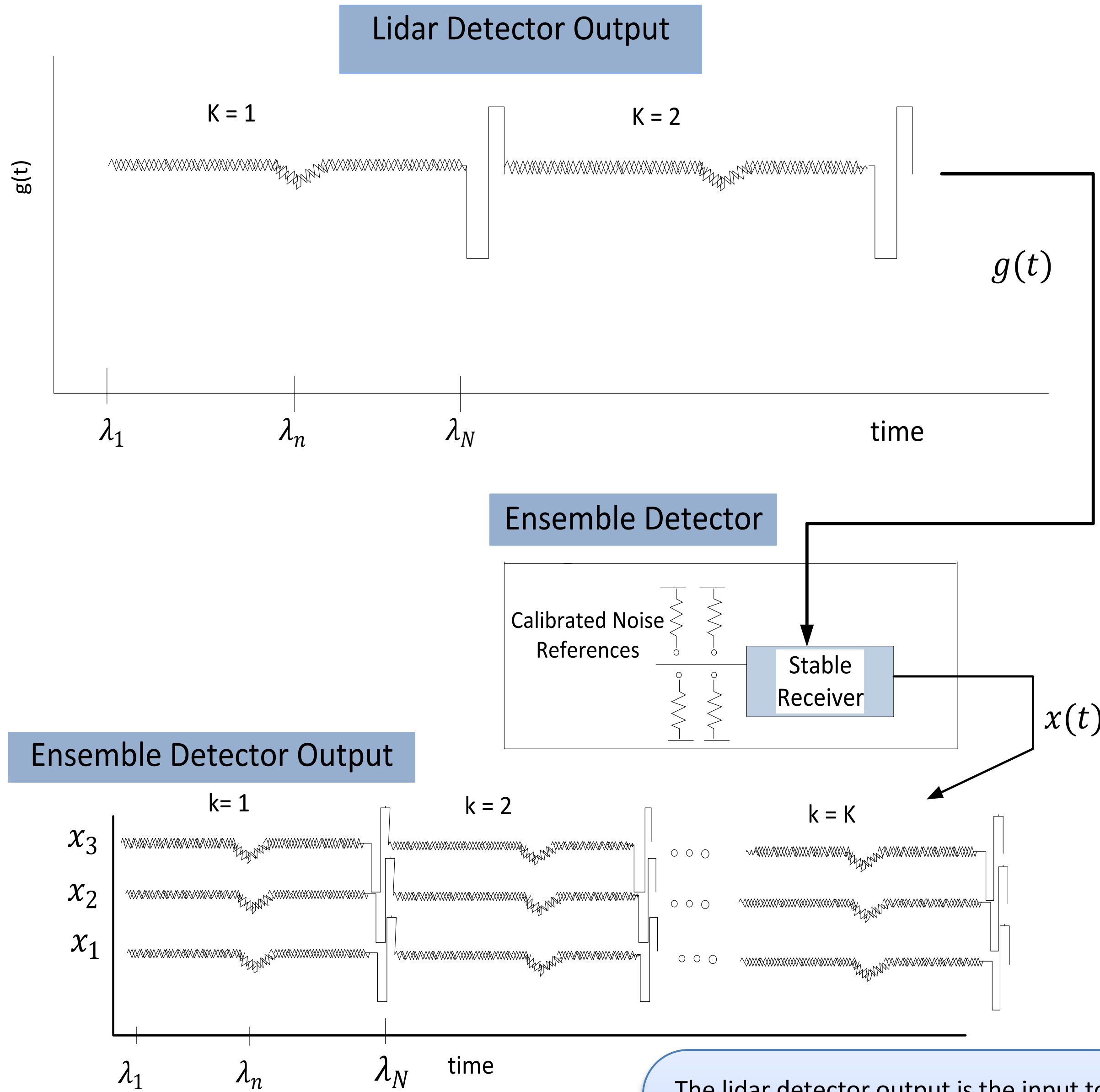
Introduction and Background

LIDAR is an active remote sensing measurement used extensively to measure small particles in the environment - such as oxygen, water vapor, and carbon dioxide. The measurement of these small particles allows scientists to better understand molecule concentration, water depth, atmospheric pressure, and overall humidity. As Schmid described, using LIDAR has several advantages. Since lidar has high accuracy rates, high point density, large coverage areas, and the ability for its users to re-sample areas quickly and efficiently, LIDAR creates the ability to map discrete changes at a very high resolution - and uniformly cover large areas very accurately, producing rapid results [1].

Additionally, NASA's Goddard atmospheric research branch uses LIDAR instruments to measure the Co_2 column absorption. Abshire discussed that the LIDAR instruments use two tunable pulsating laser transmitters, allowing for simultaneous measurement of absorption from a Co_2 absorption line in the 1570 nm band, O_2 absorption in the oxygen A-band, and surface height and atmospheric backscatter in the same path [2].

On the other hand, because of signal interference and environmental noise in the atmosphere, non-stationary stochastic noise develops during the LIDAR measurement of Co_2 absorption. Non-stationary noise is defined as noise with a time variant. As Shelley pointed out, a non-stationary process is one in which the joint probability distribution of the process changes when shifted time [3]. Besides, some stochastic processes, such as audio signals, financial data, and biomedical signals, are non-stationary - meaning the variance and mean change over time. For example, speech is a non-stationary process generated by a time-varying system.

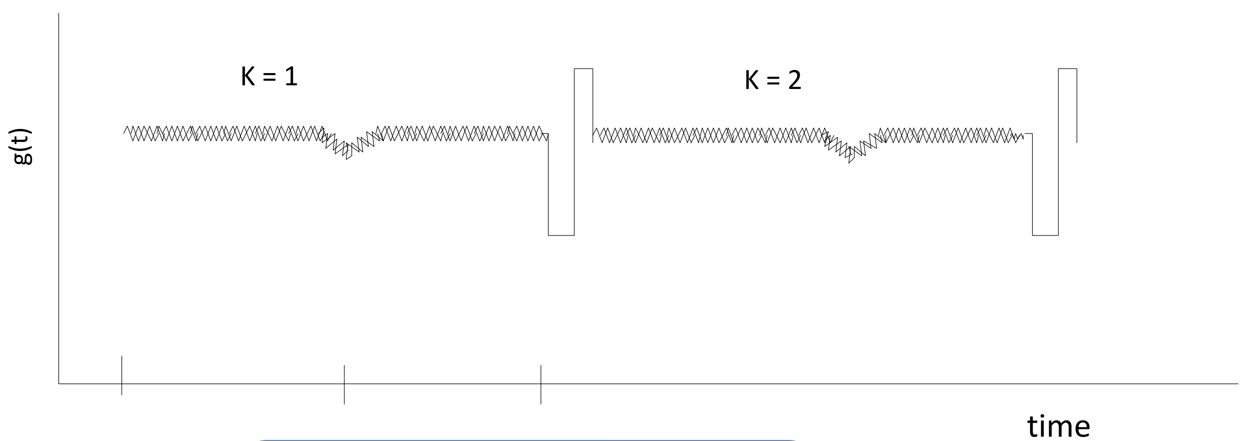
Many different approaches are introduced to model a non-stationary process using the time varying system. As mentioned earlier, two of these methods are the calibration algorithm and Ensemble Detection Analysis. Application of both can improve the modeling and analysis of non-stationary processes. As described by Paul, Ensemble detection is a technique used by mixing calibrated noises together to produce an ensemble measurement set, yielding much to the study and analysis of the non-stationary process[4].



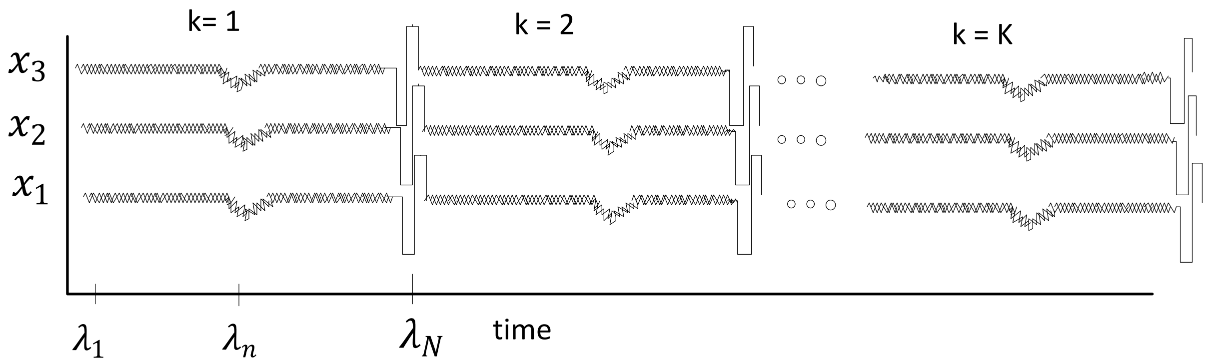
The lidar detector output is the input to an Ensemble Detector. The output of the Ensemble Detector mixes with the lidar output with calibrated noise reference; as a result, it produces an ensemble set of measurements of the Lidar output.

Methods

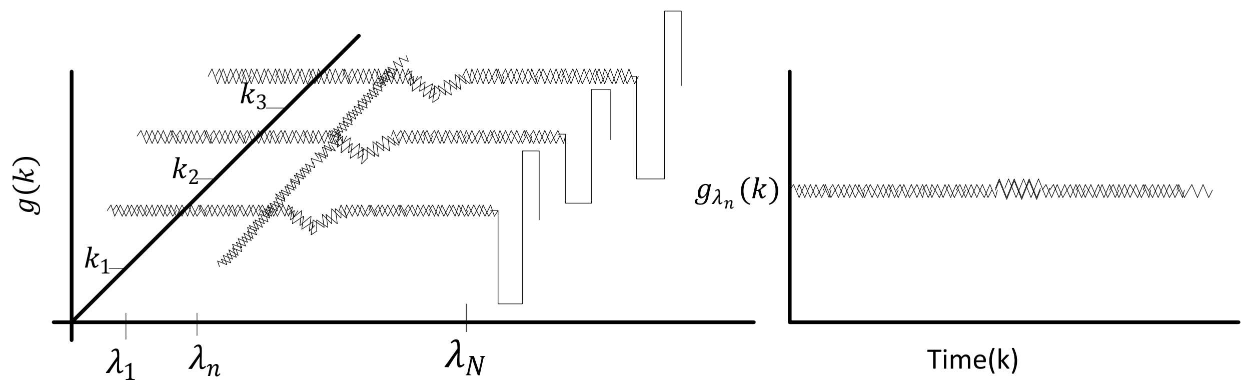
1. Modulate the Lidar wavelength over a range λ_1 *to* λ_N .
2. Mix Ensemble Detector and the Lidar output with calibrated noises references.
3. Produce ensemble detector output.
4. Decimate the detected signal into a time sequence of spectral measurement
5. Apply Least Mean Square calibration algorithm across the spectrum measurement.
6. Estimate non-stationary fluctuation signal.



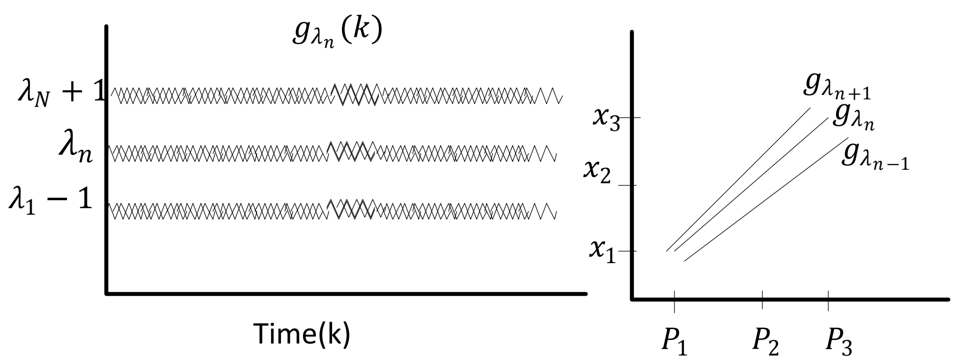
The Lidar wave length is modulated over a range λ_1 *to* λ_N covering the spectral band of interest. Absorption of the trace gas appears in the spectra.



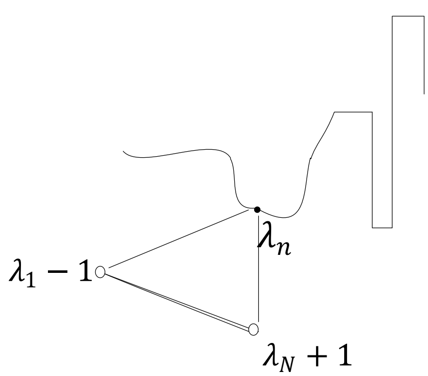
The lidar output with calibrated noise references thus producing an ensemble set of measurements of the lidar output.



The detected signal is decimated into a time sequence of spectral measurements. At a given wave length non-stationary fluctuations appear in the time sequence. These fluctuations corrupt the estimation of the strength of absorption line being measured.



Adjacent wavelength measurement is used to estimate the center wavelength using least mean square calibration algorithm. The algorithm is commonly used to remove non stationary fluctuations in receivers use in microwave radiometer.



Graph and Result

$$x_j(t,\xi) = N\left(0,\sigma_j^2\right) \quad 0 < \xi \le J, 0 \le t_i \le t_{n,} J$$
$$= number\ of\ realizations, \xi\ \epsilon\{\xi_1,\ \xi_2, \ldots\ \xi_J\}$$

$$g(t) = G_o\left(1 + \tilde{g}(t)\right) \qquad non - stationary\ lidar\ wavelength$$

$$P_x = g(t) * x_j^2(t_i, \xi_j)$$

$$P_x - Power(Ensemble\ Detector\ output)$$

$$\tilde{g}(t) = f(\{P_1, \sigma_1^2\}, \{P_2, \sigma_2^2\}, \ldots, \{P_J, \sigma_J^2\}),$$
$$\tilde{g}(t) \rightarrow estimate\ nonstationary\ fluctuations$$

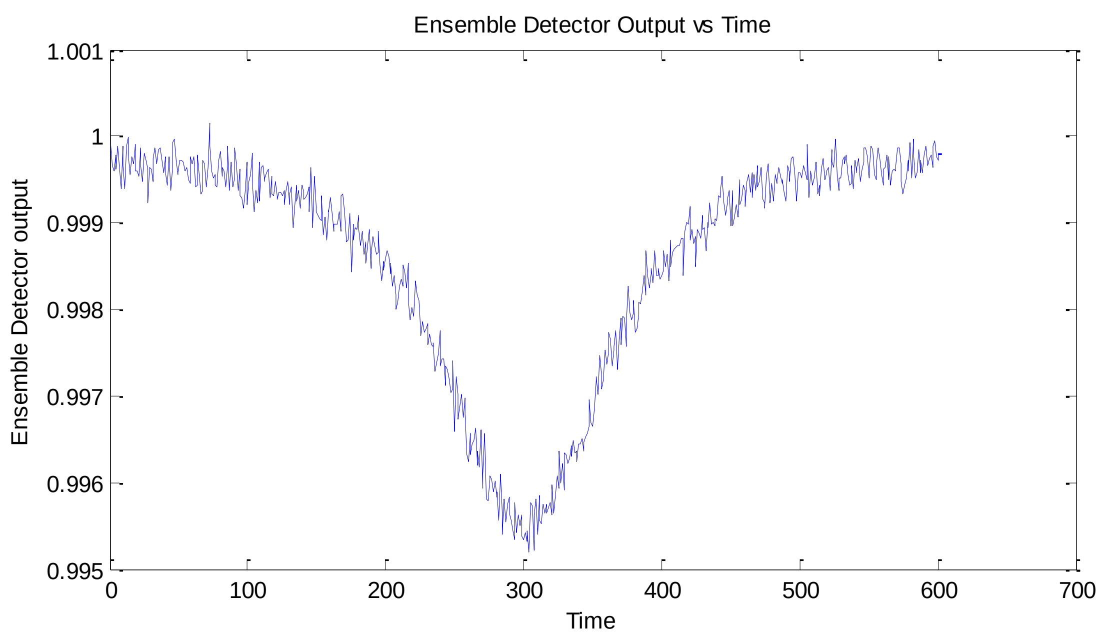


Figure 1: The output of Ensemble Detector mixes with the lidar output with calibrated noise.

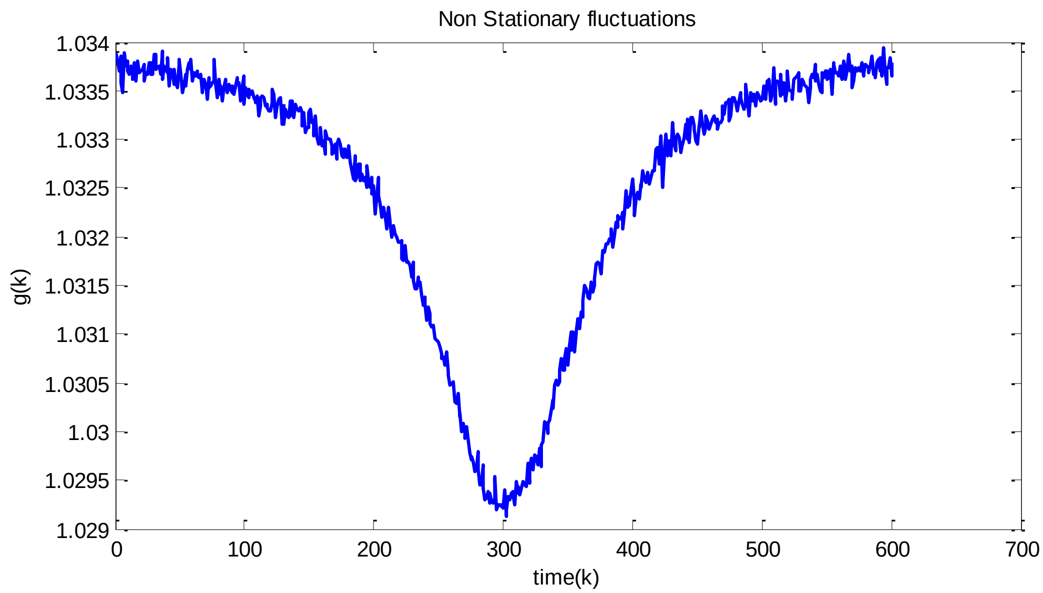


Figure 2: Non Stationary instrumental fluctuations contribute to errors in retrieval of trace gas concentration

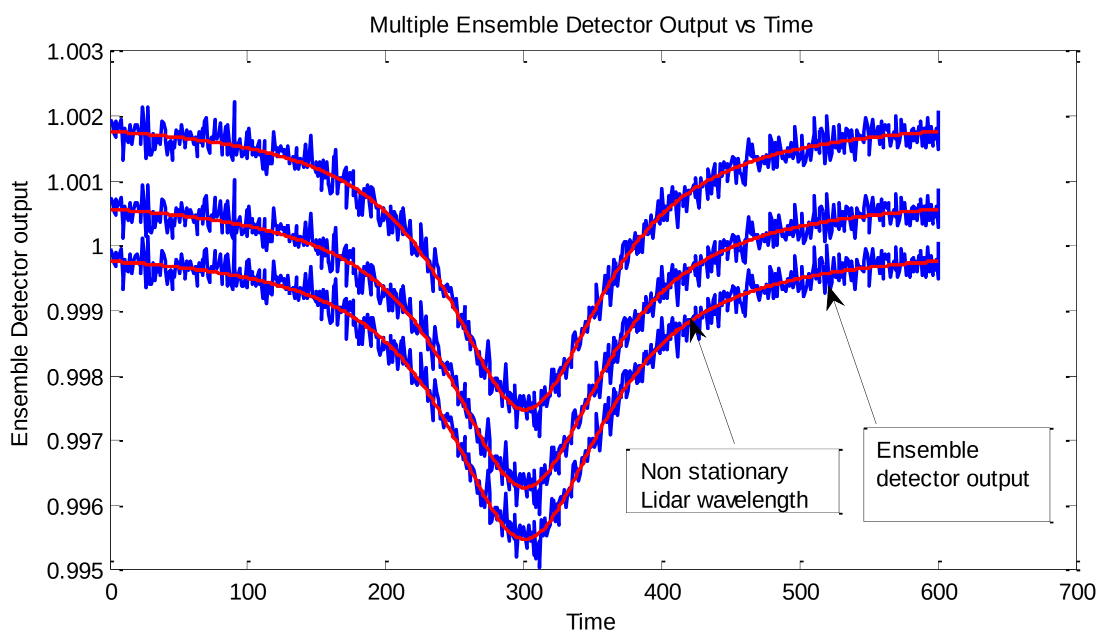


Figure 3: The output of Ensemble Detector mixes with the different amplitude of lidar output

Conclusion

1. At a given wavelength, non-stationary fluctuations appear is detected in the time sequence.
2. The detected non-stationary stochastic noise is filtered
3. By increasing the number of Ensemble detector, more fluctuation corrupt signal is identified
4. Gain fluctuation appears on each noise reference measurement
5. Measurement uncertainty is calculated by taking the given lidar non-stationary noise fluctuation and the estimate non stationary instrumental noise fluctuation

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