AeroMap: LiDAR for Real-time Aerosol Mapping and Control

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Abstract: LiDARs have been used for decades for the detection and monitoring of dust from a remote location. INO has been involved for over 15 years in the development of multiple LiDAR platforms that are targeting aerosols detection in particulates as well as gaseous formats. The LiDAR technology has been identified for its potential to better understand the production and movement of breathable dust with respect to miner working positions or monitor dust distribution behavior to identify the sources and transport of dust in large areas. Tests performed in the CDC/NIOSH simulated coal mine Long Wall and Continuous Miner galleries have confirmed this potential. The particular LiDAR platform used includes 4 optical heads that can capture simultaneously 4 LiDAR signal from 4 different lines of sight. One of the optical head is mounted on a Pan&Tilt Unit to allow mapping of dust dispersion. In the Long Wall Gallery, the LiDAR has demonstrated its ability to detect dust movements and to measure the displacement speed of dust cloud in turbulent conditions at different air velocities when looking along a fixed line of sight. It has been possible to show good temporal correlation between LiDAR relative assessed concentrations and measurements from NIOSH samplers located in the vicinity of LiDAR laser beams. This has allowed calibration of the LiDAR measurements within the range of temporal and spatial changes of concentrations in short periods of time or distances. The capability of the LiDAR to scan a volume to map the dust distribution within this volume has also been demonstrated in both galleries.
OCIS codes: (280.1100) Aerosol detection; (280.3640) Lidar (280.1120) Air pollution monitoring

1. Introduction

This work is related to the use of a LiDAR (Light Detection And Ranging) to perform mapping of aerosol dust dispersion in industrial and environmental contexts. More specifically, it presents the use of a small and easily deployable LiDAR platform (AeroMap) that can be used indoor as well as outdoor for monitoring over ranges from few meters to hundreds of meter. Examples of the use of this platform to perform standoff monitoring of particulate emissions during coal underground mining operational processes are presented below. The capabilities to map dust emissions in real-time and to calibrate LiDAR measurements are also illustrated. These capabilities are targeting the development of the LiDAR as a tool to better understand and address the worker exposure to breathable coal dust.

LiDAR uses backscattering of light to get a remote and distributed measurement of the relative quantity of dust particulates. They have been used for more than 30 years to monitor the dispersion of dust as well as gases in the atmosphere. INO has been involved for over 15 years in the development of multiple LiDAR platforms that target aerosols detection in particulates as well as gaseous formats. These developments have led to AeroMap, a compact and easily deployable LiDAR [1,2], which optical head is mounted on a Pan&Tilt unit to allow mapping of dust dispersion.

Assessing the effectiveness of dust controls during mining is a complex task due to several factors. Some of the issues that affect this understanding include 1) the presence and movement of mining equipments which restrict placement and recovery of samplers, and 2) the large area to be monitored which degrades the confidence of data collected with a limited number of samplers being representative of actual conditions. Exposure to breathable dust in mineral extraction operations is a recognized occupational hazard and may cause disease to miners. NIOSH has facilities allowing simulating dust generation and dispersion in coal mining operations. Both INO and NIOSH have combined their capabilities in this work to perform an evaluation of the LiDAR to become a valuable tool for the coal mining industry.

The objectives of the experiment have been defined by the CDC/NIOSH and are as follows: “In simulated conditions of underground coal mine operations, the goal is to demonstrate that the LiDAR can be used as a tool to better understand the production and movement of respirable dust with respect to miner working positions or monitor dust distribution behavior to identify the sources and transport of dust in large areas”.

2. Methods and Results

To achieve the objectives mentioned above, a working protocol has been developed and the simulated conditions were performed for different:

- gallery configurations (Long Wall Gallery, see figure 1, and Continuous Miner Gallery),
- ventilation speed flows,
- dust generation rates (controlled through ventilation speed flows),
- and locations (applies only to Long Wall Gallery),
- dust suppression/control techniques: water sprays and scrubber (applies only to the Continuous Miner Gallery).

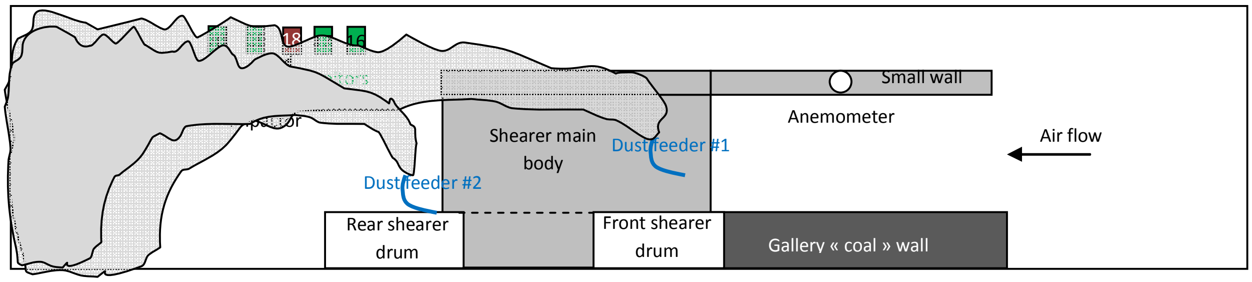

Figure 1 : Schematic top view of the simulated Long Wall Gallery with the generated dust plumes from the dust feeders.

The mapping capabilities of the LiDAR are illustrated in figure 2. It is a radar-like representation of the Long Wall gallery viewed from the top. The motion of the air stream goes from left to right. The front feeder of coal dust is illustrated with a white dot and is directed toward the bottom of the figures. The contour of the dust distributions at two different air speeds shows that at higher air speed (900 fpm) the dust forms a narrower cone of dispersion than at smaller air speed (500 fpm). It also appears that the dust concentration is lower at higher air speed than at lower air speed. This is normal since the dust feed rate is the same in both cases while the higher air speed dilutes more the dust. The decrease in concentrations from left to right also indicates that the source of dust is upstream at the left in the gallery.

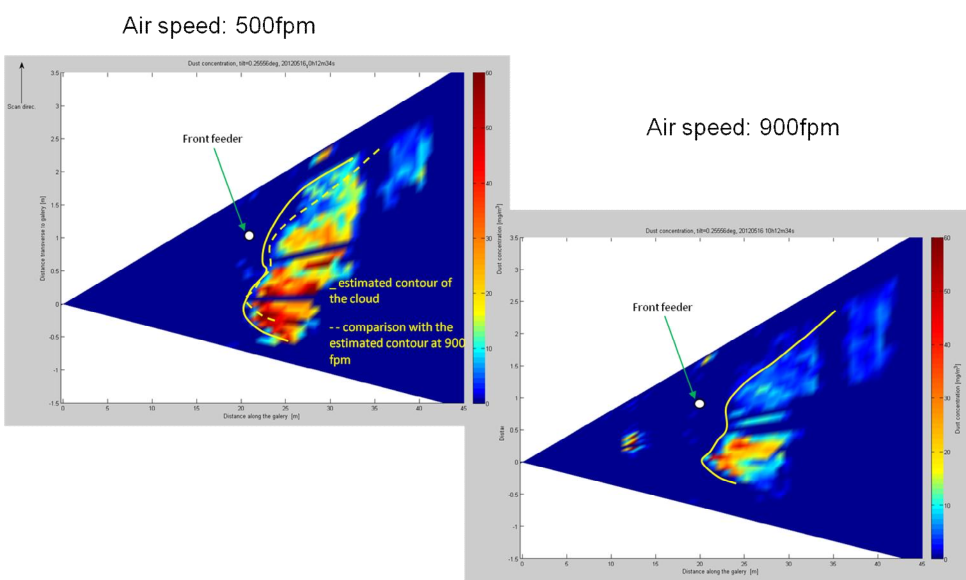

Figure 2 : Top view of the dust concentration map in the Long Wall Gallery from the generated dust plumes from the front dust feeder at two different air speeds. The map is displayed with distance transverse to the gallery vs. distance along the gallery while the color indicates the concentration.

Results obtained in a simulated Continuous Miner Gallery, not presented here, have also shown the LiDAR capabilities to illustrate dust motion differences while applying different dust control methods such as the use of water spray, scrubber, and different air speeds.

Figure 3 illustrates the relative concentration measurements from the LiDAR, at a distance of 29.75 m, compared to the NIOSH monitor (#17) positioned in vicinity (0.5 to 1.5 m) the LiDAR sampling point. The LiDAR results are based on assessed concentration from Mie theory for a given dust particle size measured by an impactor, and a given complex index of refraction of coal dust and density from the literature [3]. The extinction of the LiDAR laser beam integrated over its path length has been obtained from the transmission measurements of the laser beam reflected from walls and structures within the gallery with and without dust. This extinction combined with the LiDAR signal backscattered by the dust has been used to obtain the mass concentration along the laser path.

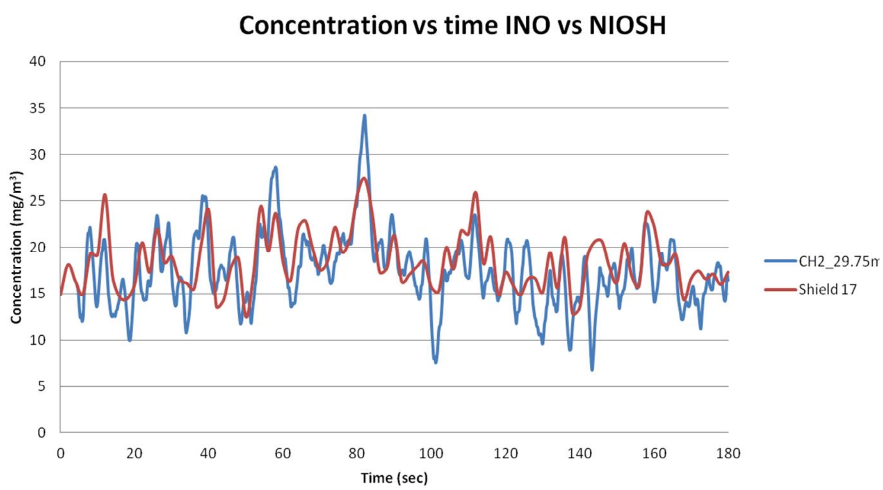

Figure 3 : Illustration of the measured dust concentration temporal behavior of the LiDAR measurements showing good agreement with respect to the concentration monitors used by the NIOSH.

It can be seen that, overall, the temporal correlation is good and that a calibration of the LiDAR measurements would be possible provided that the LiDAR is synchronized to the NIOSH monitor within one to two seconds.

3. Summary

Results obtained with a compact portable LiDAR, called AeroMap, in a simulated Long Wall Gallery have shown the capability to map the dust production and motion within the gallery. The possibility to calibrate the LiDAR results with a local dust monitoring device have also been demonstrated by the good temporal correlations between AeroMap and fixed point aerosol monitor measurements.

AeroMap has also proven to be easily deployable since measurements have been performed within 1 hour from transport case unpacking to first measurements in the simulated Continuous Miner Gallery not reported here.

Future work on AeroMap will be performed to enhance the sensitivity and to provide automated calibration using an in-situ aerosols sensor. Targeted applications include fence line monitoring of aerosols for residential zones located close to industrial zones.

4. Acknoledgements

The tests described in this work have been performed at CDC/NIOSH/OMSHR installations on Cochrans Mill Road in Pittsburgh, Pennsylvania under contract #200-2012-M-42405.

5. References

[1] Daniel Cantin, Pierre Cottin, François Babin, Nicolas Hô, Bruno Bourliaguet, 13th United States/North American Mine Ventilation Symposium, 2010, Hardcastle & McKinnon (Eds).

[2] See http://www.ino.ca/Docs/Documents/publications/technical/lidar-remote-sensing/COMM-100129_FICHE%20HYDRA_dust%20remote%20sensing%20system_EN.pdf (accessed March 2013).

[3] James G. Speight, Handbook of coal analysis, p. 114.