AGLITE: A Portable Lidar for Agricultural Production Practice Optimization

G. E. Bingham*, T. D. Wilkerson, V. Zavyalov, S.S. Connelsen, J. Swasey, J. Hacock

Space Dynamics Laboratory, Utah State University Research Foundation, North Logan, UT 84341-1947

Abstract – High quality air is important to the well-being of humans, animals, and plants. Agricultural operations produce a variety of particulates and gases that influence air quality. Agriculture-generated particulate matter can enter human lungs and cause pulmonary problems. Animal production operations produce gaseous emissions such as ammonia, odor-causing volatile organic compounds, hydrogen sulfide, greenhouse gases (methane, nitrous oxides) and airborne pathogens. These emissions can negatively impact human health, property values, and the environment. SDL is developing an advanced lidar, portable system tailored to provide measurements required to quantify emission rates, determine emission factors, and to develop management practices for their mitigation.

Keywords: Lidar, pollution, confined animal feeding operations, aerosol plume characterization

AGLITE is a vehicle-portable, rugged, computer-controlled, modular unit designed for easy deployment in various vehicles, including aircraft. The system utilizes a fixed vertical telescope with a steering mirror used as an azimuth-elevation beam director. For agricultural assessment, the most common lidar scan pattern employees repeated vertical scans of the atmosphere on the upwind and downwind sides of an aerosol emission source. When combined with wind speed information, this pattern allows the estimate of source flux rates using the input minus output flux difference method. This technique is being investigated for the determination of aerosols source contributions into the boundary layer from limited fetch and complex terrain systems that typically characterize confined animal feeding operations (CAFO). A three-color Nd:YAG laser with output at the three characteristic wavelengths, 1064, 532, and 355 nm, is used in AGLITE to allow aerosol plume characterization. The high rep rate, low pulse energy laser provides 3 W output at 10 kHz at 1064 nm and 1 W at 532 and 355 nm. The high rep rate laser choice was made to allow eye safe operations at the close ranges required for agricultural studies. AGLITE is designed to provide 6 m range gate resolution to provide the high resolution detail required to support confined animal feeding operations studies.

This paper details the design and performance of AGLITE, and demonstrates the capability of modern remote sensors in the multiple dimension problem required to systematically reduce agricultural impacts on regional air quality.

1. INTRODUCTION

Due to concentrations of animals at large feeding facilities, Concentrated Animial Feeding Operations (CAFO) are being investigated by government environmental regulators as major sources of air and water pollutants.

The federal government regulates concentrated animal feeding operations under its point-source pollution permitting regulations. A major determinant of whether an operation must apply for a permit is the number of animals at an individual lot or facility. Both land treatment practices that are used to disperse the injurious by-products of agricultural production, and the CAFO themselves are under scrutiny. Given the uncertainties about the amount of pollution from CAFO, lack of enforcement of existing regulations, localization of problems, and possible alternatives for addressing the pollution, appropriate regulatory and producer response is uncertain (Wilson et al., 2001). Existing strategies rely heavily on the stewardship ethic of the livestock producers. Regulations currently assume that all CAFO owners and operators will develop and implement technically sound, economically feasible, site specific nutrient and waste management plans. However, regulations also are based on the number and quantity of pollutants that "cross the boundary" of the property owners. A major uncertainty – in addition to that of the amount of waste being generated – is the transport effectiveness between the source and the boundary line.

The United States Department of Agriculture, Agriculture Research Service (ARS) has developed a program to measure the level of pollutants crossing the CAFO boundary and the source and transport phenomenon associated with the release. The variation in environmental conditions associated with these transport activities make it practically and economically unfeasible to study or monitor actual pollution source strength using point sensors. The Space Dynamics Laboratory (SDL) at Utah State University has teamed with the ARS researchers to bring space technology remote sensing hardware into the study plans to track and quantify CAFO pollutant transfers. The first pollutant class targeted in this cooperative program is production aerosols. Much of this concern is centered on organic gases such as ammonia and methane as well as microscopic particles in the range of 2.5 – 10 microns in diameter. These particles are also commonly referred to as PM2.5 and PM10 (PM for 'particulate matter'). According to the U. S. Environmental Protection Agency, PM2.5 and PM10 contribute to a number of respiratory illnesses and are the major cause of reduced visibility conditions (haze) seen in many parts of the country. Because ammonia is often involved in forming these small particulates, trace gas monitoring is a key part of this study. In addition to regulatory issues, the larger scale dusts and smells associated with these production facilities also cause significant neighbor complaints. The SDL Agricultural Lidar (Aglite) was developed to track the development, transport and particulate size history of CAFO airborne pollutant plumes.

* Tel: (435) 797-4600; Fax: (435) 797-4366; email: gail.bingham@sdl.usu.edu

2. AGLITE DESCRIPTION

The AGLITE-LIDAR instrument is a three-wavelength lidar system being designed and constructed at SDL under contract from the ARS. Its purpose is to implement a novel new approach to making measurements of gas and particulate pollutants released into the atmosphere by agricultural operations. Once operational, it will provide a means whereby the total flux of pollutants being emitted by agricultural facilities might be measured. This approach is valid even for facilities that may cover many hectors. The amount of light that is scattered back and received in the telescope depends on the particle concentration, the backscatter coefficient and the intensity of the laser source. The particle concentration is a simple idea; however, the backscatter coefficient is comprised of many different things. This coefficient depends on the wavelength of the laser light, the properties of the particles, such as their composition and size distribution, and also the environmental conditions, such as the ambient humidity. The theoretical basis that drives the science of this instrument is that by analyzing the scattered light received at the detector, the equations can be worked backwards to arrive at the initial information such as the particle size or the composition (Bockmann, 2001; Bockman et al., 2004). To make this backwards extrapolation possible, some reasonable assumptions must be made about the environment and the particles. Ultimately, it is also necessary to take measurements with several different wavelengths of light so that the information can be compared to arrive at a solution for the desired unknown. The key components of the system and their functions are shown in **Error! Not a valid bookmark self-reference.**.

Table 1. Aglite system major components and functions.

Component	Description
3-color Laser	NdYAG laser operating at the wavelengths 1064, 532, and 355 nm
Detectors	Photon detectors that could operate at the given wavelengths
Beam Steering	Actuators manipulate the pointing mirror to scan the laser beam and receiving telescope beam through 270° azimuth and 45° in elevation.
Photon Counting Data Acquisition	The data system implements photon counting approach to detect low return signals in full daylight with hazy or dusty conditions.
Digital Camera	A camera to follow the field of view of the lidar and capture digital imagery of the downrange scene to track plumes and identify safety hazards.
Thermal Control	Sensors as well as fans and heaters to control system temperature
Laser Energy Sensors	Sensors to monitor the outgoing laser energy continually during normal system operation and telemeter this data to the analysis system.
Synchronizer	Electronics to synchronize the laser firing with the data acquisition systems and the detector gates.

Another critical issue of this system is the eye safe range of the instrument (Spinhirne, 1993). Unlike most pollutant measurement lidars, this system is operational in the area where animals and people could be injured if it is improperly designed and operated. Aglite's physical arrangement is shown in **Error! Reference source not found.**. Significant design effort (Cornelsen, 2005) has gone into making Aglite as sensitive as possible, while keeping it eye safe at the shortest possible range. To make the system as eye safe as possible, Aglite is based on a micro pulse, diode pumped, high repetition rate laser operating at 1064 nm, 532nm and 355nm, simultaneously. The laser is rated at 500 mW at each wavelength, at its nominal 10KHz operating frequency, providing 50 μJ per 35 ns pulse. Aglite is eye safe at all three wavelengths at 0.5 Km. The 28 cm telescope collection system is designed to allow full daylight operations at ranges up to 5 km.

The Aglite system is trailer mounted, and the beam director is elevated above the vehicle roof to provide a 270° azimuth by

45° elevation measurement volume. The AGLITE electronics system has the task of coordinating all the functions of the lidar. It controls the firing of the laser and synchronizes this with the data collection systems. Once collected, the data is averaged and reduced before it is stored and made available to the operator for further analysis. The electronics system also controls the beam director to perform the scanning operation. The system also includes the light detectors, a digital camera, and sensors to internally monitor the instrument. The total electronics package integrates all of these components and establishes semi-automated computer control over them. The operator interface occurs at the computer terminal, and once the system is configured it runs without the need for further user intervention.

Because the Aglite system will have to operate at some distance from the rest of the experimental activity, the system is designed to allow full remote operation, including monitoring of any hazard that should approach the beam in the eye safety region. Information from Aglite and its co-aligned video camera system are transmitted to the system control center by wireless control links. The system control and data processing system organization is shown in Figure 2.

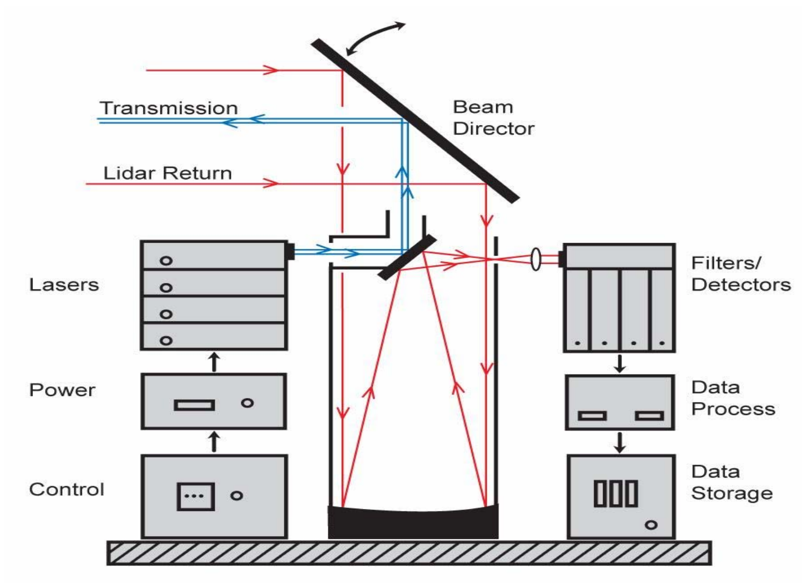

Figure 1. Aglite physical schematic, showing the co-aligned, telescope and bean direction system.

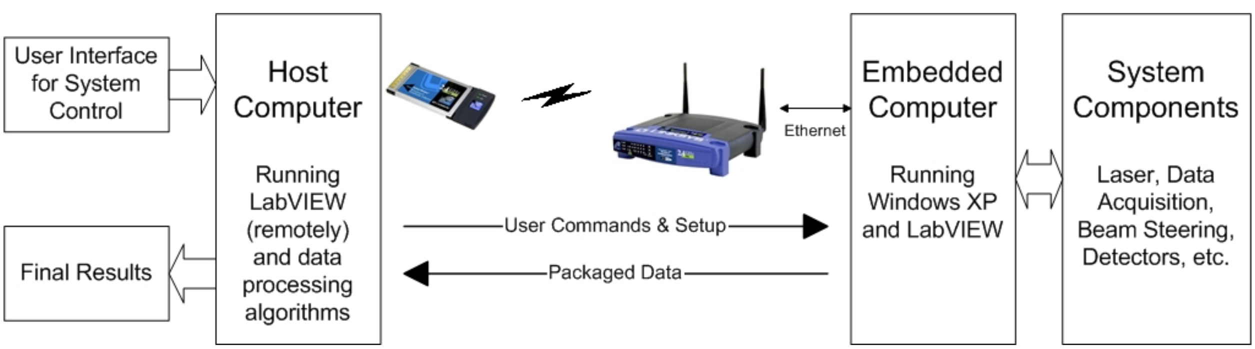

Figure 2. The Aglite system control and analysis center is located away from the lidar system and collects data and monitors safety via wireless links

3. APPLICATIONS

The primary application of the Aglite sensor is to support pollutant flux measurements in the complex terrain that is generated by the structures associated with most CAFOs. Until accurate flux measurements and transport equations can be developed, regulators are limited to inaccurate models for limit setting, and producers are left to guess the net effect of their mitigation efforts. Cooper et al. (2003) used a water vapor Lidar to determine vertical gradients in humidity above fairly uniform target surfaces, but the underlying assumptions are not satisfied at most CAFO sites. Specifically, while these calculated surface fluxes from these gradients used known theoretical relations and make various uniformity assumptions, the method relies on an independent measurement of turbulence intensity. Area measurements of this variable are difficult and not sustainable in a long term monitoring situation. Hipps and Zehr (1995) demonstrated a more sustainable approach that does not require turbulence knowledge. This method measures changes in lidar determined vertical concentrations between the upwind and downwind sides of the source area. The flux is determined from the area between the curves and mean wind, which can also be derived from the lidar data. To complete this approach, the system must measure to height where curves converge, and the measurements need to be repeated often enough to track variations in the source. The advantage of the lidar system in this measurement technique is that for most locations, the upwind concentration can be derived from the beam detected profile concentrations on either side of the target source. This approach is being tested in an experimental measurement sequence this summer, using simulated and actual CAFO sources.

4. CONCLUSIONS

High quality air is important to the well-being of humans, animals, and plants. Agricultural operations produce a variety of particulates and gases that influence air quality. The Space Dynamics Laboratory (SDL) at Utah State University has teamed with USDA ARS researchers to bring space technology remote sensing hardware into the study plans to track and quantify CAFO aerosol pollutant transfers. The Aglite system is a small, easily portable lidar system that can track and characterize pollutant plumes. Providing the producer with accurate measurements of the pollutant fluxes crossing their boundaries under various management approaches will help them reduce emissions and allow regulators to properly set emission standards.

5. REFERENCES

Bockmann, Christine, “Hybrid regularization method for the ill-posed inversion of multiwavelength lidar data in the retrieval of aerosol size distributions,” Applied Optics. Vol. 40, No. 9, pp. 1329 – 1342, 2001.

Bockmann, Christine, Ulla Wandinger, Albert Ansmann, Jens Bo¨ senberg, Vassilis Amiridis, Antonella Boselli, Arnaud Delaval, Ferdinando De Tomasi, Max Frioud, Ivan Videnov Grigorov, Arne Hågård, Matej Horvat, Marco Iarlori, Leonce Komguem, Stephan Kreipl, Gilles Larcheveque, Volker Matthias, Alexandros Papayannis, Gelsomina Pappalardo, Francesc Rocadenbosch, Jose Antonio Rodrigues, Johannes Schneider, Valery Shcherbakov, and Matthias Wiegner, “**A**erosol lidar intercomparison in the framework of the EARLINET project. 2. Aerosol backscatter algorithms,” APPLIED OPTICS Vol. 43, No. 4 pp. 977 – 989, 2004.

Cooper, D.I., W.E. Eichinger, J. Archuleta, L. Hipps, J. Kao, M.Y. Leclerc, C.M. Neale and J. Prueger, “Spatial source-area analysis of three-dimensional moisture fields from lidar, eddy covariance, and a footprint model,” Agric. For. Meteorol. 114: 213-234, 2003.

Cornelsen, Scott S., “Electronics Design of the AGLITE_LIDAR Instrument,” MS Thesis. Utah State University, Logan, UT. 84341, 2005.

Hipps, L.E. and D.F. Zehr, “Determination of evaporation from integrated profiles of humidity and temperature over an inhomogeneous surface,” Boundary-Layer Meteorol., 75: 287-299, 1995.

Spinhire., J. D. “Micro Pulse Lidar,” IEEE Trans. on Geoscience and Remote Sensing, V 31, pp 48-54, 1993.

Wilson, John D., Thomas K. Flesch, and Lowry A. Harper, “Micro-meteorological methods for estimating surface exchange with a disturbed windflow,” Agricultural and Forest Meteorology 107 (2001) 207–225, 2001.