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ScienceDirect

Energy Procedia 110 (2017) 396 – 401

Energy Procedia

1st International Conference on Energy and Power, ICEP2016, 14-16 December 2016, RMIT University, Melbourne, Australia

Detection of Volatile Organic Compound Emissions from Energy Distribution Network Leaks by Bistatic LIDAR

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Abstract

Energy distribution networks are subject to various problems resulting in uncontrolled environmental releases or leaks. These leaks are of particular concerns due to the hazardous nature of the transported commodity. Consequently, a significant research interest lies in the design of effective leak detection technologies. Light Detection and Ranging (LIDAR) systems are very promising as they enable remote detection at considerable distances. This paper presents an innovative LIDAR measurement system capable of detecting leaks from Unmanned Aerial Vehicles (UAV). The transmitter consists of a tuneable laser source mounted on the UAV and the receiver consists of a calibrated reflector and a passive imaging system mounted on an unmanned ground vehicle. This bistatic layout allows for a significant increase in range. The system employs an open-path Differential Absorption LIDAR (DIAL) measurement technique for selected molecular species. The proposed bistatic LIDAR system offers notable advantages compared to monostatic DIAL and in situ leak detection systems based on extraction sampling technology.

Peer-review under responsibility of the organizing committee of the 1st International Conference on Energy and Power.

Keywords: LIDAR; laser; UAV; energy network; energy distribution; fault detection.

1. Introduction

Energy transport and distribution networks are affected by a number of issues resulting in anything between the unintended environmental release of a commodity to major explosions with loss of human lives [1]. Pipelines used in the oil and gas industry are of particular concern due to the hazardous characteristics of the involved commodity, which can consist of natural gas as well as various other Low/High Vapor Pressure (LVP/HVP) hydrocarbon products. HVP pipelines, in particular, contain flammable products with a vapor pressure above ambient pressure at the

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Peer-review under responsibility of the organizing committee of the 1st International Conference on Energy and Power.
doi:10.1016/j.egypro.2017.03.159

operating temperatures [2]. An accident causing the contents of these pipelines to ignite is susceptible of either of the following outcomes: fireballs and jet fires (immediate ignition), pool fires (delayed ignition of buoyant vapor clouds), flash fires (delayed ignition of a dispersing vapor/air mixture of limited size or far from stoichiometric conditions) and vapor cloud explosions (ignition of a vapor/air mixture of sufficient size and close to stoichiometric conditions).

Most leak detection methods traditionally employed in long pipelines involve pressure or flow transducers [3-5], but Light Detection and Ranging (LIDAR) and imaging techniques are progressively being considered [6-10]. An early detection of pipe leaks by remote/standoff systems can allow a timely intervention, mitigating the risk of ignition. Models to estimate hazard extents are also crucially dependent on accurate estimations of flammable release concentrations. Ensemble average concentrations are most frequently adopted in these models due to the unavailability of information regarding the fluctuations and distribution of atmospheric hydrocarbon concentrations during an uncontrolled/unintentional release event [2]. A detection of the actual concentrations can allow to accurately estimate the hazard extent in real time.

Currently available leak detection systems are affected by various limitations, especially when stand-off monitoring of Volatile Organic Compounds (VOC) is considered. In-situ sampling devices produce point measurements and are not well suited to characterize the spatial distribution of VOC leaks. Additionally, installation and maintenance costs increase considerably when sampling systems are employed for monitoring very long pipelines. Furthermore, at increasing distances from the emission sources, the accuracy of numerical emission dispersion profiles is significantly degraded by aerodynamic advection and diffusion processes. On the other hand, stand-off platforms, such as aircraft and satellites, are typically very expensive and frequently not available, when and where needed, to detect leaks and measure the VOC concentrations.

A stand-off leak detection system based on bistatic LIDAR is proposed here based on previous research [11-14]. In particular, in [15, 16] we presented the key features of a bistatic LIDAR emission measurement system, discussed the rationale supporting its development, introduced both laboratory and on site calibrations and calculated a preliminary error budget. An in situ calibration technique was also introduced, employing a second ground-based LIDAR emitter and electro-optics photo-detectors. This paper discusses the application of the proposed measurement system to detect leaks from energy transport and distribution networks. The measurement techniques proposed here show very high potential for the attainment of the required accuracy and precision for the stand-off detection of VOC with flexible and inexpensive robotic systems, meeting the needs of several energy sectors.

2. Stand-off bistatic leak detection system overview

The proposed stand-off leak detection and VOC measurement system consists of two non-collocated components. The laser transmitter (TX) is mounted on a small autonomous aircraft, along with suitable TX optics for beam expansion and collimation. The receiver (RX) components are mounted on a ground roving vehicle, and consist of a calibrated target surface of high and diffused reflectance exhibiting Lambertian behaviour and a Near Infrared (NIR) camera with RX optics mounted on a rail. As conceptually depicted in Fig. 1a, molecular absorption and scattering are highly wavelength-selective and enable Differential Absorption LIDAR (DIAL) measurements. The autonomous aircraft and the ground roving vehicle are deployed at selected follow pre-determined trajectories based on the layout and extent of the energy distribution network to be monitored. A Bidirectional Reflectance Distribution Function (BRDF) is derived for the calibrated target surface. Both molecular and aerosol concentrations in the atmosphere introduce absorption and scattering phenomena that affect the laser beam propagation. The principle of operation of the leak detection system is depicted in Fig. 1b. A suitable objective and highly selective filters are used as part of the RX optics on the NIR camera to detect the laser spot energy on the target and to generate a Pixel Intensity Matrix (PIM) in a high resolution greyscale format.