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High-Altitude, Aerial Natural Gas Leak Detection System

Technology Status Assessment

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Introduction

With support by the Department of Energy, Physical Sciences Inc. (PSI) has initiated a project to develop and demonstrate a laser-based sensor able to rapidly and autonomously, from a high-altitude platform, survey for leaks from natural gas transmission pipelines over large and remote areas. The ultimate goal of the technology is to enable surveys from unmanned aerial vehicles (UAVs) operating as high as 80,000 ft. The sensor is an enhancement of the Remote Methane Leak Detector (RMLD) developed recently by PSI. The RMLD is an example of a standoff sensor using the technique of Tunable Diode Laser Absorption Spectroscopy (TDLAS). Laser light emitted from a transceiver illuminates a passive surface (i.e. the ground). Using the well-understood principles of Wavelength Modulation Spectroscopy (WMS), the RMLD signal processor analyzes the signal embedded in the small amount of laser light reflected back to the transceiver and quantifies the amount of gas along the laser path.

The purpose of this Technology Assessment is to evaluate the state-of-the-art in laser-based and aerial natural gas leak detection, and understand how the enhanced RMLD technology to be developed provides a significant advancement.

Background

The US natural gas transmission system comprises approximately 250,000 miles of pipeline, 1700 transmission stations and 17,000 compressors. Maintaining the security and integrity of this system is a continual process of searching for, locating, and repairing leaks. Performing leak surveys is very labor intensive, in part because all currently used leak survey tools, including the traditional Combustible Gas Indicators (CGI) and Flame Ionization Detectors (FID), as well as the relatively recent Optical Methane Detection (OMD), must be physically immersed within a leak plume to detect it. CGI and FID tools both draw gas into a combustion chamber and analyze the products of combustion to quantify local gas concentrations. The OMD projects an infrared beam across a short (~1 m) optical path open to the ambient air ("short path"), and determines by spectroscopy the concentration of gas within the optical path. The short optical path must encompass the gas to detect it. Short-path TDLAS, configured optically like an OMD but with better sensitivity, has been utilized for leak detection.

These techniques can and have been used for airborne leak surveying. To perform these surveys, a light airplane or helicopter flies no higher than a few hundred feet above the pipeline. Significant leaks create a plume that is intercepted by the aircraft and detected by the on-board instrumentation.

The RMLD is a novel configuration of the highly sensitive and selective TDLAS. It projects onto a distant surface the infrared beam emitted by a telecommunications-style diode laser. An optical fiber cable connects the laser to the transceiver which transmits the beam and receives scattered laser light. It senses the path-integrated concentration of methane between the transceiver and the illuminated surface. Because the RMLD is intended for use in walking leak surveys, it was designed to be handheld, lightweight, and power efficient. To accommodate these attributes, the sensor has a maximum range of about 100 feet, making it unsuitable for leak surveying from an aircraft. The current project will enhance the RMLD technology capability, extending its range to several thousand feet in a fashion that can be further extended to tens of thousands of feet, thereby enabling rapid airborne survey of large areas. To modify the RMLD for use in the airborne platform, three aspects of it will be modified: 1) the transmitted laser power will be increased by use of an optical fiber amplifier; 2) the size of the optical receiver will be increased; and 3) the laser wavelength will be changed.

Alternative Leak Sensing Technologies

To understand the advantage offered by the amplified RMLD, we compare below the attributes of various technologies available for leak surveying. The attributes of interest include: 1) the capacity for remote detection, meaning that the sensor need not be in close contact with the leak plume; 2) capability for survey from a moving platform, be it a surface vehicle or an aircraft; and 3) suitability for airborne surveying. If suitable for flight, a maximum altitude is given, if known.

Combustible Gas Indicators (CGI)

Principle of Operation: Catalytic Combustion of Gas Sample
Sampling Method: Extractive (response time few seconds)
Sensitivity: Typically measures percentage gas concentration
Advantages: Characterizes high concentrations of gas
Disadvantages: Does not detect low concentrations; sampling probe must be embedded within gas plume. Senses all combustible gases, not only natural gas.
Suitable for remote leak surveying: No
Suitable for mobile leak surveying: No – too slow and insensitive
Suitable for airborne leak surveying: No.

Flame Ionization Detectors (FID)

Example: Heath Consultants Model DP4
Principle of Operation: Measures electrical conductivity of a flame burning carbon compounds
Sampling Method: Extractive (response time few seconds)
Sensitivity: Typically measures parts per million
Advantages: Sensitive detection of low gas concentrations
Disadvantages: Sampling probe must be embedded within gas plume. Senses all combustion gases, not just natural gas.
Suitable for remote leak surveying: No
Suitable for mobile leak surveying: Only by traveling through leak plume
Suitable for airborne leak surveying: Only by traveling through leak plume.

Optical Methane Detector (OMD)[1]

Example: Heath Consultants
Principle of Operation: Absorption of Infrared Light by Methane
Sampling Method: Short Open Path or Extractive
Sensitivity: Typically measures parts per million

Advantages: Sensitive detection of low gas concentrations; Open path probe eliminates sampling time lag of extractive sensors. Less sensitive to gases other than methane.
Disadvantages: Sampling probe must be embedded within or encompass gas plume
Suitable for remote leak surveying: No
Suitable for mobile leak surveying: Only by traveling through leak plume
Suitable for airborne leak surveying: Only by traveling through leak plume.

Short-Path TDLAS

Example: Boreal Laser
Principle of Operation: Differential Absorption of Infrared Light by Methane; single laser with temporal wavelength modulation
Sampling Method: Open Path or Extractive
Sensitivity: Typically measures < 1 part per million
Advantages: Sensitive detection of low gas concentrations; Open path probe eliminates sampling time lag of extractive sensors, low power consumption. Senses only methane.
Disadvantages: Sampling probe must be embedded within or encompass gas plume
Suitable for remote leak surveying: No
Suitable for mobile leak surveying: Only by traveling through leak plume
Suitable for airborne leak surveying: Only by traveling through leak plume.

RMLD/Stand-off TDLAS[2,3]

Example: Physical Sciences Inc./Heath Consultants RMLD
Principle of Operation: Differential Absorption of Infrared Light by Methane; single laser with temporal wavelength modulation
Sampling Method: Detection of laser backscatter from topographic targets
Sensitivity: Measures path-integrated concentration, typical detection limit ~ 5ppm-m
Advantages: Fast, sensitive detection of low gas concentrations; optical transceiver can be outside of gas plume, low power consumption. Senses only methane.
Disadvantages: New technology; plume must be encompassed between transceiver and topographic scattering surface; range limited to 100 ft
Suitable for remote leak surveying: Yes
Suitable for mobile leak surveying: Yes, under development
Suitable for airborne leak surveying: Current research project to extend range to >10,000 ft.

Active Gas Correlation Radiometry[4]

Example: Ophir DUOthane
Principle of Operation: Differential Absorption of Infrared Light by Methane and Ethane;
Sampling Method: Detection of infrared backscatter from topographic targets
Sensitivity: Measures path-integrated concentration, typical detection limit ~ 50 ppm-m
Advantages: Detection of low gas concentrations; optical transceiver can be outside of gas plume. Senses two components of natural gas.
Disadvantages: New technology; plume must be encompassed between transceiver and topographic scattering surface; range limited to ~ 500 ft

Suitable for remote leak surveying: Yes
Suitable for mobile leak surveying: Yes
Suitable for airborne leak surveying: Under development. Maximum altitude ~500 ft.

Differential Absorption LIDAR (DIAL)[5,6]

Examples: ITT (fixed-wing aircraft with mapping and imaging), Lasen (helicopter), Gas Technology Institute (surface vehicle with imaging)
Principle of Operation: Differential Absorption of Infrared Light by Methane and Ethane; multiple lasers provide temporal wavelength modulation
Sampling Method: Detection of laser backscatter from topographic targets
Sensitivity: Measures path-integrated concentration, expected detection limit ~ 5ppm-m
Advantages: Fast, sensitive detection of low gas concentrations; optical transceiver can be outside of gas plume
Disadvantages: New technology unproven for leak survey applications; plume must be encompassed between transceiver and topographic scattering surface; relatively high power consumption (compared to TDLAS).
Suitable for remote leak surveying: Yes
Suitable for mobile leak surveying: Yes, under development
Suitable for airborne leak surveying: Yes, under development. Maximum altitude ~2000 ft.

Passive Multi-wavelength Radiometry[7]

Examples: En-Urga, PSI/AIRIS
Principle of Operation: Differential Absorption of Infrared Light by Methane;
Sampling Method: Passive detection of infrared light emitted by topographic surfaces. Tunable filters or several fixed filters provide differential absorption measurement.
Sensitivity: Measures path-integrated concentration, typical detection limit ~ 500 ppm-m
Advantages: No active illumination source, plume imaging possible
Disadvantages: New technology; plume must be encompassed between transceiver and topographic emitter; relatively poor sensitivity compared to active techniques; subject to cross-species interference; relatively slow; limited dynamic range; quantification difficult due to gas temperature effect
Suitable for remote leak surveying: Yes
Suitable for mobile leak surveying: Yes, under development
Suitable for airborne leak surveying: Possibly. Not currently in development. Maximum altitude ~3000 ft.

Summary

The technologies currently available or under development for aerial leak surveying are summarized in Table 1. They fall into two broad categories: In-situ techniques requiring the aircraft to fly through a leak plume in order to detect the leak, and remote sensors based on optical standoff detection. The latter includes both active and passive optical sensors, all based on absorption of infrared light as it passes through the leak plume. Differential absorption, i.e. measurement of infrared absorption at two or more wavelengths, enables sensitive and selective detection of methane and, in some cases, ethane. The more-sensitive active techniques include the use of wavelength agile (i.e. tunable) lasers, or multiple lasers of fixed wavelength, or broadband (i.e. non-laser) infrared sources with narrow-band filters.

All of the current optical sensors have the potential for use in airborne surveys, and some have been tested in that mode, but they are limited to altitudes of about 2000 ft agl. The amplified RMLD offers the potential to detect leak plumes having path-integrated concentrations > 1000 ppm-m from altitudes up to 80,000 ft. From this altitude, entire cites could be continuously monitored from a UAV.

Table 1 – Technology Summary

Technology	Pros	Cons
In-situ Sensors		
Flame Ionization Detector	• Established Technology • Sensitive Detection	• Extractive • Non-Specific
Optical Methane Detector	• Proven Technology • Open-Path	• Must encompass plume
Short-path TDLAS	• Very sensitive and specific • Open Path	• Must encompass plume
Stand-off Sensors		
Active		
Stand-off TDLAS	• Very sensitive and specific • Remote detection	• Range limited to 100 ft
Gas Correlation Spectrometry	• Specific to natural gas • Remote detection	• Less sensitive than TDLAS • Range limited to 500 ft
Differential Absorption LIDAR	• Very sensitive and specific • Remote Detection Range ~ 2000 ft	• Complex Operation • Unproven
Passive		
Multi-Wavelength Radiometry	• No active illumination source • Imaging possible	• Poor sensitivity and specificity • Limited dynamic range • Difficult to quantify

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