Standoff Sensing of Natural Gas Leaks: Evolution of the Remote Methane Leak Detector (RMLD)

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Abstract: Development of a handheld standoff laser-based sensor developed specifically for inspection of municipal natural gas pipelines is described. The Remote Methane Leak Detector is fundamentally a Differential Absorption LIDAR system using Wavelength Modulation Spectroscopy.

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1. TDLAS overview

Gas sensors based on Tunable Diode Laser Absorption Spectroscopy (TDLAS) enable sensing trace concentrations of many critical gases in a broad array of applications. TDLAS gas analyzers rely on well-known spectroscopic principles and sensitive detection techniques coupled with advanced diode lasers, and often with optical fibers. The principles are straightforward: Gas molecules absorb energy in narrow bands surrounding specific wavelengths in the electromagnetic spectrum. At wavelengths slightly different than these “absorption lines”, there is essentially no absorption. By (1) transmitting a beam of light through a gas mixture sample containing a quantity of the target gas, (2) tuning the beam’s wavelength to one of the target gas’s absorption lines, and (3) accurately measuring the absorption of that beam, one can deduce the concentration of target gas molecules integrated over the beam's path length.

Typically, each TDL system is built using a laser having a specific design wavelength chosen to optimize the sensitivity to a particular target gas while minimizing sensitivity to other gases. Figure 1 illustrates a commonly utilized TDLAS system architecture. The laser's fast tuning capability is exploited to rapidly and repeatedly scan the wavelength across the selected gas absorption line. When the wavelength is tuned to be off of the absorption line, the power transmitted through the gas mixture is higher than when it is on the line. The periodic power modulation, combined with well-established noise reduction techniques known as frequency or wavelength modulation spectroscopy (WMS) and Balanced Ratiometric Detection (BRD), yields a precise measure of the amount of target gas along the laser path [1,2].

![Fig. 1. TDLAS gas detector system.](image)

2. RMLD purpose

Natural gas distribution companies continually survey gas pipelines to detect small leaks and correct them before they become dangerous. Currently employed leak survey tools include Combustible Gas Indicators (CGI), Flame Ionization Detectors (FID), and the relatively recent Optical Methane Detection (OMD). All of these devices require the sensor to be physically embedded within the gas leak plume detect the leak. Thus, to find leaks the surveyor
generally must travel directly over the pipeline - a costly and at times difficult process often requiring the service person to enter a property and walk the entire length of the service line.

As pictured in Figure 2, standoff detection by the RMLD enables detecting leaks from afar, reducing survey time and enabling more efficient use of manpower. The RMLD system includes a handheld optical transceiver and a shoulder-mounted control unit. The two sections are connected by an umbilical cable bearing an optical fiber and a few wires. The laser beam, projected from the road or sidewalk above the path of the pipeline, illuminates a passive surface (i.e. the ground or a building wall). By analyzing the signal embedded in the small amount of laser light reflected back to the transceiver, the RMLD deduces the presence or absence of gas along the laser path. Only when gas is detected does the survey crew walk the pipeline to localize the leak. The time to survey non-leaking pipes is reduced to seconds, Preliminary estimates for walking survey operations show savings in the range of 25% to 40%, resulting in cost savings within the US of millions of dollars annually. The RMLD can also detect natural gas inside a building or confined space with clear access, as well as in difficult to reach areas, such as gas pipelines under bridges, backyard mains and fenced in areas.

Fig. 2. Illustration of surveyor inspecting a gas pipeline.

3. RMLD development

Development of the RMLD required a significant advancement in the TDLAS state-of-the-art. Specific requirements were: the complete sensor system, i.e. the transceiver and control unit including batteries, must not weigh more than about 6 pounds; it must operate continuously for an eight-hour workday on a single battery charge; it must have a standoff range of at least 100 ft; within the standoff range, it must detect gas leaks as small as those detectable with current FID units with a 0.1s response time; it must function in ambient temperatures between 0 and 50 °C; it must be rugged, splash-proof and weather-resistant; and it must be comfortable for the surveyor.

To meet these challenges, the RMLD has now undergone three stages of evolutionary development, the Engineering Prototype (EP), Advanced Prototype (AP), and the Beta Prototype (BP) which is now entering production [3,4]. Four AP units were built in 2002 for field evaluation. Between April and July 2003, five utility companies completed the first field testing cycle using two APs. Each field test lasted about two weeks. Portable FIDs were used to validate RMLD results, and all leaks were fully documented. During the four month test period over 140 documented leaks were encountered, representing typical distribution leaks in both residential and commercial areas served by both low and high pressure systems. Although the two RMLD AP units exhibited some differences in performance, this initial test program was considered to be a success – the leak detection capability of the better performing RMLD was at least as good as portable FI. An AP unit in a typical survey operation is pictured in Figure 3.

Based on user feedback after conclusion of AP testing, much of the RMLD external configuration was redesigned to accommodate surveyor ergonomics. In particular, the weight of the transceiver was reduced by relocating a User Interface display from the transceiver to the control unit. The umbilical connecting the two units, a source of user frustration in AP, was ruggedized. Most significantly, the means of gripping and supporting the transceiver were improved to allow a surveyor to use the instrument comfortably day in and day out. To achieve a satisfactory design while meeting performance needs, a variety of weighted transceiver models were fabricated and tested by users to arrive at an acceptable form, feel, and balance. The resulting plastic housing protects the optics from the external environment, and protection from damage by dropping is provided by supporting the optical assembly on shock mounts within the housing. The housing form also provides an appropriate product appearance that is compatible with the manufacturer’s brand. Figure 4 shows the BP transceiver in use.
4. RMLD technology

Through the evolution from EP to BP, we created: 1) a TDLAS Control Unit incorporating all functions needed for Wavelength Modulation Spectroscopy on a single 6-in. square printed circuit board with digital signal processing (DSP) and an embedded microcontroller; 2) a compact and lightweight optical transceiver; and 3) ergonomic enclosures for the two components.

All of the laser control, thermal control, signal processing, and data reporting functions are performed on the Control Unit board, which draws only 1.5 W of power. The system is typically powered by two AA-sized rechargeable Li-ion batteries. Battery charge control circuitry is built onto the circuit board. The total cost for all board components, excluding the laser, is a few hundred dollars.

The TDLAS Control Board offers three forms of communication with users or other equipment: 1) A serial port, using the RS-232 protocol, is used for system configuration, and can output data. This port is not used during normal operation. 2) A System Peripheral Interface (SPI) data link which carries information to a User Interface (UI) panel. The UI in the RMLD displays path-integrated concentration, system status information, and provides keys for adjusting performance parameters; 3) An audio output. In RMLD, which is intended to be used as a simple alarm rather than a quantitative analytical tool, audio is the primary means of communication.

The transceiver optical design balances several requirements: 1) it transmits and receives enough laser power to provide a measurable return signal from scattering by topographic targets; 2) the transmitted beam is everywhere eye-safe, achieved by limiting transmitted laser power to less than approximately 10 mW and assuring that the diameter of the exposed beam is never smaller than approximately 1 cm; 3) the divergence of the transmitted beam is selected to underfill the receiver field-of-view yet sample gas amorphous gas plumes at 100 ft range while minimizing speckle effects; and 4) the receiver rejects sunlight, making it insensitive to ambient illumination.

5. Conclusion

After several years of product development and design evolution, standoff detection of natural gas leaks by TDLAS is now a proven technology entering commercial production. The technology is expected to dramatically change leak survey operations. Development of the technology has advanced the state-of-the-art of TDLAS, yielding miniature low-power consumption and relatively low-cost TDLAS platforms. The TDLAS control unit described herein can be adapted to sense a host of other gases and a variety of optical configurations.

6. References