Laser spectroscopic trace-gas wireless sensor networks

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Laser-based atmospheric trace-gas sensors have great potential for long-term, real-time, maintenance free environmental monitoring in distributed Wireless Sensor Networks (WSN). We have developed a laser spectroscopy platform which enables low cost, handheld footprint, and battery/solar power to address the requirements of WSNs. A prototype sensor measures oxygen concentration in the atmosphere and is configured as an autonomous, battery powered, handheld unit with power consumption <0.3W, minimum detectable absorption of $2\times10^{-5}/Hz^{1/2}$, weight of <0.4kg (with 3.5 meter custom multipass cell), and the robustness required for long term environmental sensing applications. We have demonstrated a three node sensor network localization of an oxygen plume.

Integration of chemical sensors into WSNs become necessary in monitoring hundreds of sq. km with <0.5 sq. km resolution in such real-time applications as leak localization around geological carbon sequestration sites, industrial and natural emissions (especially methane) monitoring, agricultural monitoring, or volcanic emissions monitoring. Furthermore, application of sensor networks for unauthorized industrial emissions monitoring or implementation of an exact carbon credit trading system (e.g. the successor to the Kyoto Protocol) will require spatio-temporal resolution which is not available with current wide-area trace-gas monitoring methods.

We implement our test systems with vertical cavity surface emitting lasers (VCSELs), which operate at a wavelength of 766nm with optical output power of 0.2mW. The laser tunes over 10 O_2 absorption lines via thermal tuning from -10.0°C to 40°C using an integrated Peltier cooler. The line $^{P}Q_{19}(18)$ is targeted with the laser operating near room temperature for minimal power consumption.

The integrated signal processing and control system is based on a single ultra-low power 8MHz microcontroller. The controller continuously performs a digital PID servo loop on the laser temperature providing stability of 0.001°C. The laser current is driven with an onboard current source with additional sinusoidal modulation at f=16 kHz. The processor allows for three channels of real-time digital lock-in amplifier harmonic demodulation at dc, $1f$, $2f$, or $3f$ with independently controlled phase alignment. For continuous monitoring the system can autonomously lock the laser to the $2f$ absorption line (as shown in Figure 1) using the zero-crossing of the 3rd harmonic as an error signal. This method relaxes signal processing needs required in our previous systems in Ref [1] and allows for ultra-low power consumption.

The entire sensor (Figure 2) can run on 4 AA batteries for >16 hours (with continuous wireless transmission). The system also has the capability for low operational duty cycles (100nA sleep current), or can be deployed with a small solar panel for continuous monitoring.

We deployed a three node demonstration sensor network (Figure 3). A release of oxygen (<5 sec.) from a lecture bottle containing 100% oxygen created a plume while the sensors were running in real-time. The sensors were placed a few meters apart in a triangular configuration. Using time-of-flight and relative quantification, we were able to determine the approximate location of the release.

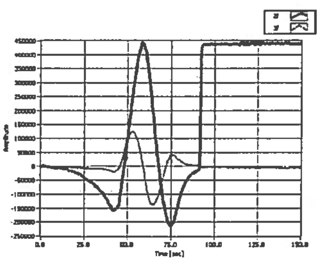

Figure 1: Line locking using integrated lock-in amplifiers. After the initial spectral scan, the system locks at 90 seconds.

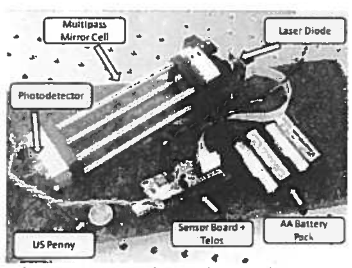

Figure 2: Complete battery powered sensor with 3.5m multipass cell.

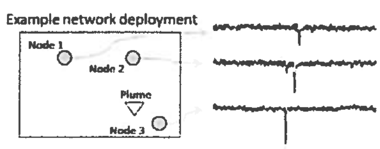

Figure 3: Example WSN based plume localization using three sensor nodes measuring O_2.

[1] S. So, G. Wysocki, J.P. Frantz, F.K. Tittel, "Development of Digital Signal Processor Controlled Quantum Cascade Laser Based Trace Gas Sensor Technology", IEEE Sensors Journal, 6, **5**, pp. 1057-1067, (2006)