Design of a mid-infrared device using HPSDS for multi-gas detection inside barns

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Abstract: We present an instrument for multi-gas measurement in the mid-infrared based on heterodyne phase sensitive dispersion spectroscopy, specifically designed for use in precision livestock farming and capable of delivering high levels of performance at ambient pressure.

1. Introduction

The purpose of this paper is to provide an overview of the design and operation of the first multi-channel molecular dispersion spectroscopy instrument that will be used to monitor ambient concentrations of methane, carbon dioxide, and ammonia in livestock barns. The reliable and continuous determination of the abovementioned gases concentrations is of key importance to ensure both animal health and product quality [1][2]. Currently, a single fixed sampling point within the facility is virtually always used to measure gas concentrations. As a result, data may not always be representative of the concentrations to which animals are exposed. The present system takes advantage of optical spectroscopy to gain a deeper understanding of the gas concentration scenario. The proposed sensing approach consists of sending three combined laser beams (harmless to both animals and human operators), each one tuned to a different wavelength for multi-gas analysis, around the barn a few centimeters above the animals' heads by using conventional optics. Although simple in principle, this measurement method is complicated by the large amount of dust particles and aerosols that cause strong intensity fluctuations in the beam path. To overcome this problem, we propose the development of a system that uses dispersion spectroscopy, rather than absorption spectroscopy, to retrieve the concentration of the different gases of interest.

The proposed approach, which is based on Heterodyne Phase Sensitive Dispersion Spectroscopy (HPSDS) [3][4], allows to retrieve gas concentrations from the measurement of the refractive index profile in the vicinity of the molecular resonance, offering remarkable advantages (compared to traditional methods) such as an inherent immunity to intensity fluctuations and linearity in the measurement of gas concentration. In addition, HPSDS is characterized by the simplicity of its implementation, which makes it an ideal platform for field deployment. The most suitable approach for operation with quantum cascade lasers (QCL) (in order to have access to the fundamental resonances of the molecules in the mid infrared) is direct modulation of the optical source intensity. It is important to add that, in order to achieve optimum performance; the modulation frequency must be within the linewidth range of the desired spectral characteristic. Therefore, very high modulation frequencies are required for ambient pressure operation, making system design challenging.

2. Instrument design and implementation

A basic block diagram of the HPSDS system is shown in Fig 1. Three QCLs with HHL packaging (Alpes Laser) are used. The operating wavelengths were selected based on technical criteria to maximize sensitivity and to select the spectral range in which the various compounds of interest can be unambiguously detected. It is also important to analyze the full width half-maximum at normal environmental conditions (pressure and temperature ambient), since these parameters will directly influence the operating requirements of the system. Specialized current and temperature controller units were used to tune the lasers to the right operation point. However, due to the high frequency requirements for the modulation of the lasers, it is necessary to generate this modulation externally and integrate it with the driver's current by means of a bias-tee circuit. In this way, the AC current can be added to the DC component to adequately drive the laser. For optimization, and considering that HPSDS systems provide optimal performance when the modulation frequencies are within the linewidth range of the spectral feature to be analyzed, the lasers are modulated at high frequency using a RF signal generator. Subsequently, a novel optical system that allows the 3 optical beams to be combined so that they can be treated as a single beam is employed. The implementation of the optical combiner is a portable architecture that minimizes the use of moving parts and in an utterly robust format. The final, multi-color, laser beam can then be sent around the barn to characterize the concentration of the target gases. On the detection side, a fast photodetector is needed to detect the interrogation signals hence creating the high-frequency beat notes. Frequency multiplexing is used to enable the detection of the three target gases simultaneously. Hence, a three channel lock-in amplifier is required. Nonetheless, an additional difficulty is to detect the phases of three very high frequency signals. Such a challenge is addressed by using a frequency down conversion stage in which a frequency mixer and an additional local oscillator are employed. When the laser is tuned across the absorption line, a phase waveform is obtained from which the gas concentration can be determined. A reference arm has been implemented and used for a first characterization of the spectral characteristics of the lasers in use. At present, efforts are focused on the assembly and construction of the complete system.

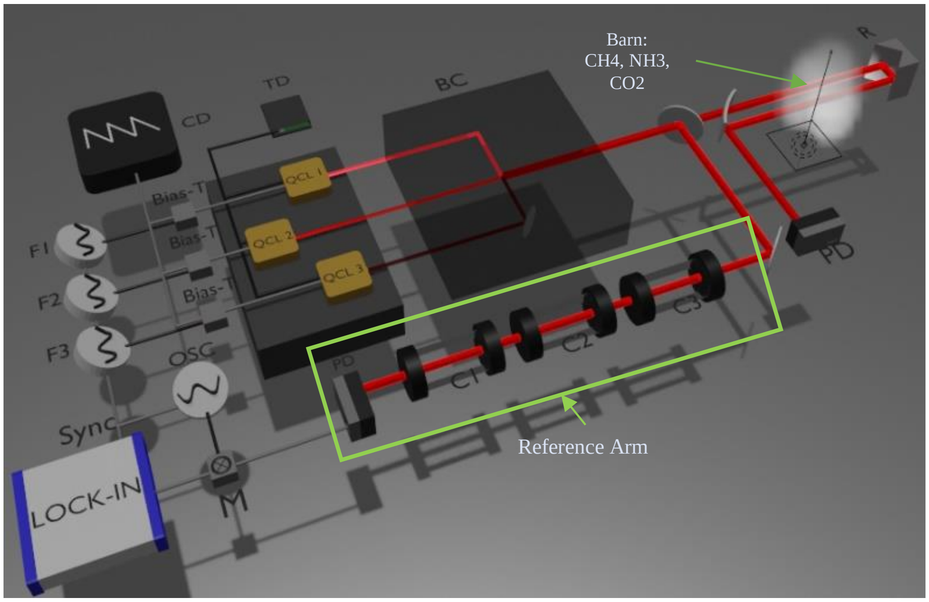

Fig 1. a) Block diagram of the implemented architecture. CD, current driver; TD, temperature driver; F1-2-3, frequency generators; BC, beam combiners; PD, photodetector; R, Reflector; M, Mixer

3. Conclusion

This paper presents a novel mid-infrared multi-gas detection system, currently under development, using heterodyne phase sensitive dispersion spectroscopy to measure real-time concentrations of various gases in livestock barns. This architecture solves several drawbacks of current systems, such as multi-gas detection under common environmental conditions inside a barn, the inherent immunity to intensity fluctuations and linearity in gas concentration.

4. References

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