

Compact supercontinuum gas spectrometer: principle and airborne field applications

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Abstract: A compact and lightweight mid-infrared supercontinuum gas spectrometer has been developed and successfully tested in airborne campaigns to simultaneously monitor the methane and water vapor concentration in the exhaust fumes of ships. © 2021 The Author(s)

1. Introduction

Optical sensing systems for environmental gas monitoring has extensively attracted the IR spectroscopy community. Since the recent advancement of broadband high-brightness light sources, the spectral window of the fingerprint of several gases of interest can be reached efficiently [1]. Within the framework of the H2020 project FLAIR (FLying ultraA-broadband single-shot InfraRed sensor), a portable spectrometer based on a compact mid-IR supercontinuum has been developed and used for airborne field tests.

2. Spectrometer

Figure 1 depicts the CAD design and the developed prototype of the supercontinuum gas spectrometer. As described in the CAD design, a collimated supercontinuum light source is intensity-modulated by an external chopper, which eliminates the intrinsic system noise thanks to lock-in detection. The light is then directed to a multipass cell (MPC) and focused on the cell entrance. The MPC is configured to have an optical path of 12m, using 40 passes over a physical length of 30cm. In turn the light emerging from the cell is collimated towards a diffraction grating. The first-order diffracted beam is imaged horizontally on the uncooled 2D PbSe-on-CMOS array camera (128x128 pixels). Notice that the beam is vertically expanded by a cylindrical lens placed in front of the camera. The main advantage of such a beam expansion is to compensate for the intrinsic fixed pattern noise and non-uniform gain of each pixel of the camera [2]. A simple averaging along the vertical camera axis returns the light transmission profile containing the gas fingerprint feature with an improved SNR (signal-to-noise ratio). A single shot measurement covers the spectral range of 34cm^{-1} with 0.7cm^{-1} resolution and, in the case of methane, the sensitivity has been measured to be below the atmospheric normal concentration ($<2\text{ppm}$).

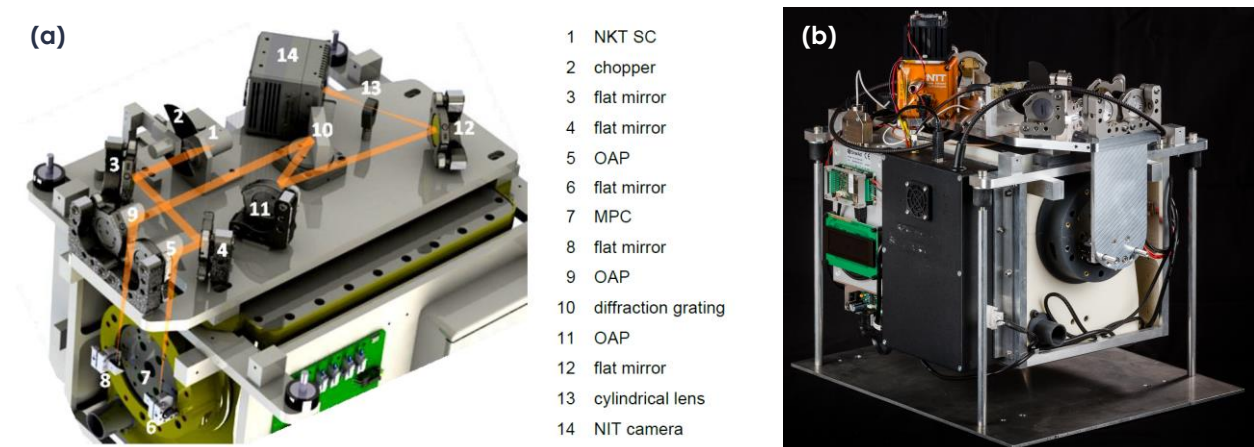


Figure 1: Supercontinuum spectrometer: (a) CAD design and (b) developed prototype.

3. Airborne field tests and Results

The goal of the first airborne test was to validate the flight-compatibility of the system as a standalone unit. As illustrated in Figure 2(a), the system, powered by a single battery, has been placed on the passenger seat of a Zeppelin and used to detect methane from an artificial point-source gas leak, which was obtained by a bottle of methane at 4%. A Teflon tube that was connected to the gas bottle was installed along a 4m-height antenna to guide the leaking gas to the air. Then, the Zeppelin was flying in the vicinity of the leak position and continuously measured the gas absorption spectrum. Notice that, when the Zeppelin was flying down towards the leak position a sharp rise of the methane concentration was measured as expected. On the other hand, when it flew away, the methane concentration dropped to the background level.

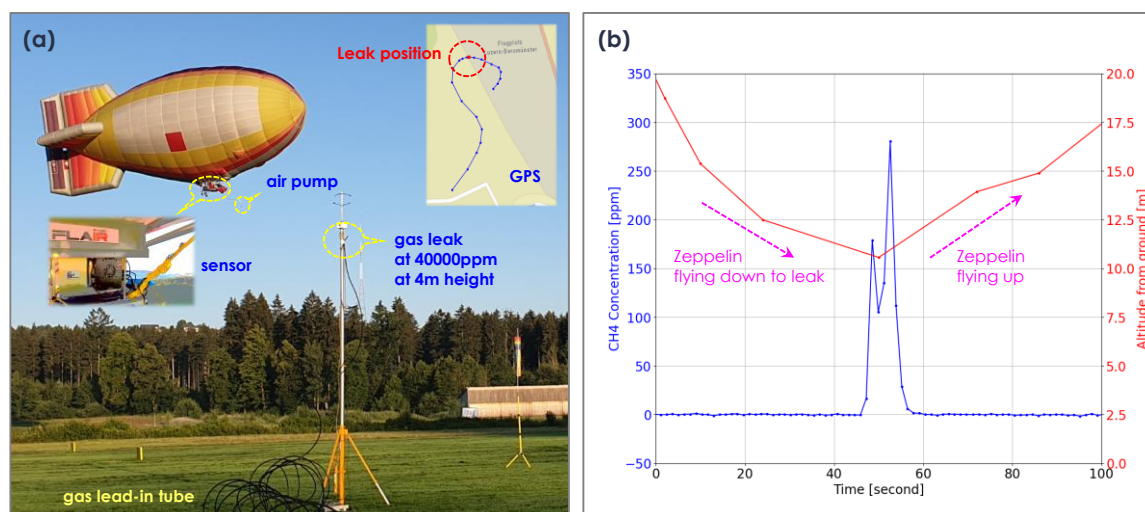


Figure 2: Airborne field test using Zeppelin for monitoring simulated methane.

A 2nd airborne field test was performed with a helicopter, as depicted in Figure 3(a). The helicopter was flying along the Kattegat channel between Denmark and Sweden to investigate in real-time the emission of methane and water vapor from the exhaust of ships. We could successfully and reproducibly measure the high emission levels of methane at approximately 20ppm from a few vessels, all of which were powered by LNG (liquefied natural gas). A commercial methane sensor (LGD Compact-A CH4 from Axetris), used as a reference, shows excellent agreement with our sensor system.

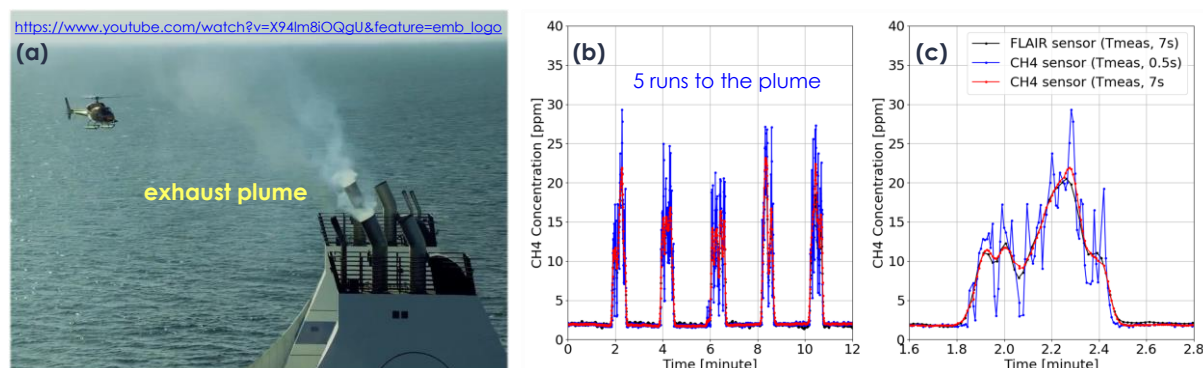


Figure 3: Airborne field test using helicopter for monitoring methane, emitted from cruising ships

To the best of our knowledge, this is the first demonstration of real-time monitoring of the methane emission from cruising ships using an airborne broadband IR atmospheric spectroscopy method.

4. References

- [1] Kubat, I., Agger, C., Moselund, P., and Bang, O., "Mid-infrared supercontinuum generation to 4.5 μm in uniform and tapered ZBLAN step-index fibers by direct pumping at 1064 or 1550 nm," J. Opt. Soc. Am. B 30, 2743-2757 (2013).
- [2] M. Kastek et al. "Technology of uncooled fast polycrystalline PbSe focal plane arrays in systems for muzzle flash detection", Proc. SPIE 9074, C31 Technologies for Homeland Security and Homeland Defense XIII, 90740A (29 May 2014); doi:10.1117/12.2053284