DOI 10.5162/SMSI2020/C2.1

FLAIR Airborne System for Multi-Species Atmospheric Gas Spectroscopy in the mid-IR

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Summary:

We present the realization of the broadband atmospheric gas spectrometer developed in the frame of the H2020 FLAIR project. The system is UAV compatible for deployment in hard to reach location. We also report on its behavior during field testing aboard a zeppelin and a helicopter tracking ship fume.

Keywords: mid-IR spectrometer, atmospheric gas spectroscopy, ship fumes, supercontinuum, MWIR uncooled camera

Background, Motivation an Objective

The World Health Organization statistics shows that approximately 7 million people are killed by air pollution related conditions every year; specifically, in Europe air pollution is presumed to be the cause of 0.3 million premature deaths. The total annual economic cost of air pollution-related health impacts is estimated to exceed USD 1.5 trillion. However, it is often a challenge to measure the level of pollutants in harsh environments and/or remote areas such as volcanic eruption, industrial fires or ship toxic fumes, which are major threat for the respiratory illness, the depletion of the ozone layer and the acid rain. The main goal of the European project FLAIR (Flying ultra-broadband single-shot InfraRed [1]) is to design and build an atmospheric gas sensing spectrometer. Thanks to its lightweight and compact form factor, the whole system including a data processing algorithm can be deployed in an Unmanned Aerial Vehicle (UAV), so that the risk assessment on the multi-species atmospheric gas can be readily performed.

System design

Fig. 1 illustrates the simplified schematic diagram of the FLAIR spectrometer. It consists mainly of 4 parts: a supercontinuum (SC) laser covering a wide wavelength range from 2 to 5 µm, which is broader than the spectrum provided by any commercial Quantum Cascade Lasers (QCLs) and/or optical frequency combs sources [2-5], a multi-pass cell (MPC) for light-gas interaction, a diffraction grating to disperse the light, and a 2D MWIR array to collect the dispersed spectrum.

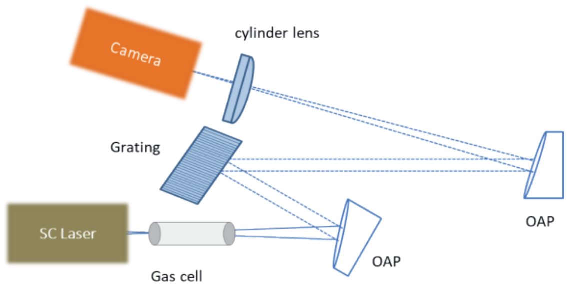

Fig. 1. Simplified schematic diagram of FLAIR spectrometer.

Fig. 2 shows the 3D CAD design of the full system. Its compact size and environmental requirements are compatible with UAVs size, mass, available electrical power and operating environment. A 30 cm long MPC, where the light is reflected back-and-forth to a 10 m interaction length, is implemented inside a thermostatic enclosure where the input air is heated above ambient temperature. The MPC is fitted with sensors for temperature, pressure and humidity measurement since such physical quantities are useful parameters to precisely compute the gas concentration from the measured gas absorption profile. The MWIR camera consists of a Vapor Phase Deposited PbSe layer on a 128x128 pixels CMOS detector array [6, 7] adapted specifically for this project.

A board computer controls the various subsystems, performs live analysis of the absorption profiles based on HITRAN models, and logs continuously the various parameter, spectra and concentrations.

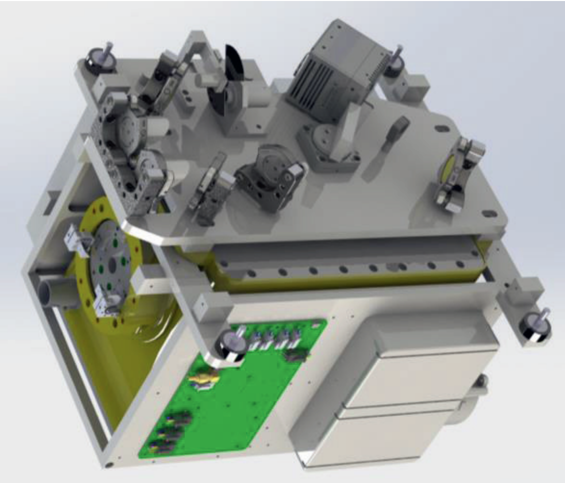

Fig. 2. CAD of the system (35 x 35 x 45 cm^3)

In the framework of FLAIR, different spectrometer designs have been investigated [5], and the final choice has been a simple diffraction grating followed by an orthogonally placed cylindrical lens to cover the whole surface of the MWIR camera. This 2-dimensional arrangement allows for the vertical averaging of the multiple horizontal copies of the dispersed spectrum, thus effectively reducing the white noise of the uncooled detector. Moreover, as this type of detectors is subject to from non-uniformity gain [6] this averaging, combined with non-uniformity correction (NUC) provided by NIT, and lock-in detection allow for a substantial SNR enhancement. Fig. 3 shows the good agreement between the measured and HITRAN-simulated methane Q-branch absorption at 500 ppb, which is below the normal atmospheric abundance.

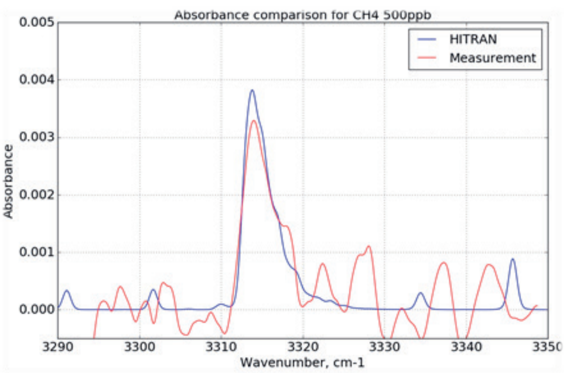

Fig. 3. Measured and HITRAN-simulated Q-branch Methane absorption profile at 500 ppb

System behavior during field testing

Two field campaigns are planned to verify the behavior of the system in real conditions. The first one consists in a flight aboard a zeppelin near Beromünster (CH) in March 2020 where some controlled methane releases will be performed.

Fig. 4. Field testing includes monitoring of ship fumes abroad the coastline of Denmark by the Explicit company (May 2020).

The second is planned for May 2020 and consists in measuring ship fumes from a helicopter (fig. 4) and benchmark the results of the FLAIR system with conventional single-specie gas detectors already available on the helicopter.

Conclusion

A compact, broadband, uncooled MWIR spectrometer for multi-species atmospheric gas analysis with dimensions 35x35x45 cm^3 is currently being assembled. Two field-test campaigns will be carried out on flying platforms this spring to validate the performances of the system in real conditions.

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