Towards the practical use of active methane imaging

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Abstract

An active gas camera is realized using an infrared camera synchronized with an interband cascade laser source at 3260 nm. The system is designed to stream concentration images in real time. A synchronization with visible and depth data allows for easy leak localization. Reliability is assured by locking the lasers wavelength to the target absorption line and an algorithm that prevents false gas information by moving objects. The setup is demonstrated on a metal background at distances between 2 m and 7 m at a methane flow rate of 40 ml/min.

1 Introduction

Methane releases in the fossil industries account for large economic losses and have a significant impact on global warming [1]. Within the wide range of possible leak detection concepts, optical gas imaging (OGI) is especially suited for the localization of leaks, the visualization of the corresponding gas cloud as well as the quantification of the amount of released gas.

2 Active methane imaging

State of the art OGI cameras use a passive approach, i.e. they evaluate the thermal background radiation using spectral filters. In contrast, active illumination with a tuneable narrow-band laser is independent from any background radiation, offers a much better spectral resolution, a lower detection limit, and shows almost no cross-sensitivities to other gases. The price for these advantages over passive OGI systems is the need for a reflective background as well as the strongly reduced measurement distance. The latter is only in the range of meters, if the whole field of view is illuminated at once, compared to km-distances that have been shown with passive systems.
The first active OGI camera was recently published by Nutt et al. [2].

2.1 Setup

In this work, a tuneable single mode DFB-interband cascade laser (ICL) around 3260 nm with 25 mW laser power is used for active illumination. Within the tuning range of the laser, one of the largest rovibrational CH_4 absorption lines can be accessed. This enables a very high sensitivity for methane detection. Stability is assured by locking the target methane line with a separate photodiode, illuminated with less than 1% of the laser light. An elaborated IR camera with integrated Stirling cooler is used for the light detection ("Image IR 8300" from Infratec, shown in black in **Figure 1**).

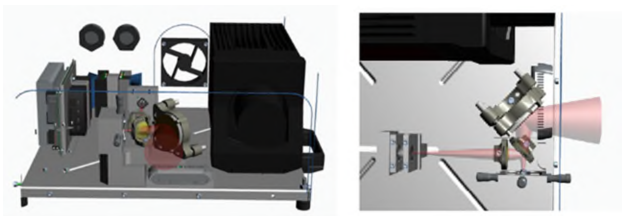

Figure 1 Left: Setup of the real time active gas camera. Right: Top view of the sketched laser light pattern in red. Less than 1% of the laser light is coupled out for locking the target gas line.

The setup is designed such that a methane visualization and quantification images are streamed in real time. At the current state at ~ 10 Hz, simultaneously with synchronized RGB and depth data.

2.2 Gas visualization & concentration calculation

For visualization and quantification of a methane gas cloud, the well-known and established procedure of tuneable diode laser absorption spectroscopy (TDLAS) is applied pixel wise.

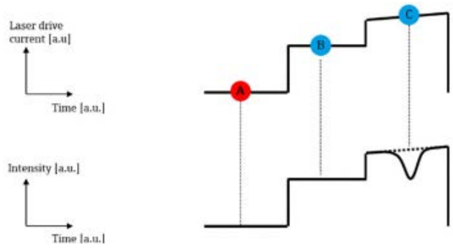

Figure 2 The applied laser drive current as well as the received intensity for an exemplary pixel are sketched. The letter A,B,C mark the time synchronization of the recorded images. If methane is within the optical path, the received intensity on image C lowers.

To extract the gas density from the Beer-Lambert absorption law, the knowledge of the back-scattered intensity with and without absorption as well as a background (BG) correction is needed. This is done by recording a batch of three single images (see **Figure 2**):
A background image (A), an image with the laser tuned "beside the absorption line" (B) and one with the laser tuned "on top of the absorption line" (C). The absorbance A is then obtained pixel wise by:

$$A = -\ln\left(\frac{C-A}{B-A}\right)$$

From the absorbance, the gas concentration as well as its visualization is then obtained easily by a real time algorithm (currently ~ 10 Hz) based on Beer-Lambert´s law in combination with a HAPI calibration, described by Strahl et al. in [3]. The laser current for the "on-top-of-line image" (C) is slightly ramped for the feedback loop that keeps the laser wavelength on the absorption line. This way, a stable gas streaming can be assured regardless of temperature changes that may be due to laser warm up or due to environmental changes.

While gas concentrations can be quantified accurately in case of fixed images, moving objects are misinterpreted as a gas information if no care is taken. By using the constantly streamed thermal background images, it is possible to filter the latter, streaming non-disturbed images regardless of moving objects.

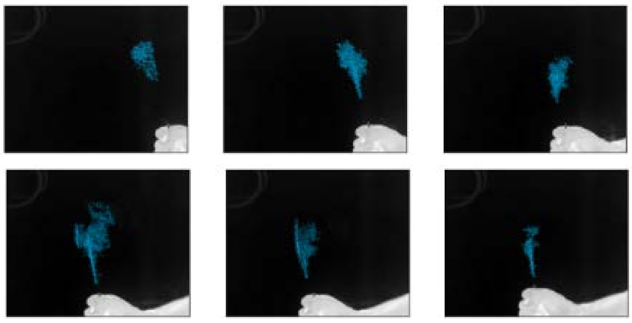

Figure 3 Shown is the visualization of a methane cloud measured with the active gas camera. Moving objects, as the hand in this example, do not yield false gas information.

2.3 Practical considerations

The suggested methane infrared spectroscopy imaging is dependent on the reflected laser light. On targets with a strong reflectivity, as e.g. metal, the suggested method yields highly sensitive gas responses for reasonable working distances. **Figure 4** demonstrates the live images on distances between 2m to 7m at a methane flow of 40 ml/min (100 % CH_4). However, on targets with poor reflectivity and/or strong thermal radiation, as e.g. hot concrete, the signal is too weak to work with, limiting the usage of this method in practical applications. While theoretically an increased laser power could overcome this limitation in the future, it is the mid infrared ICL laser diodes that are currently not available with significantly more output power than the used 25 mW.

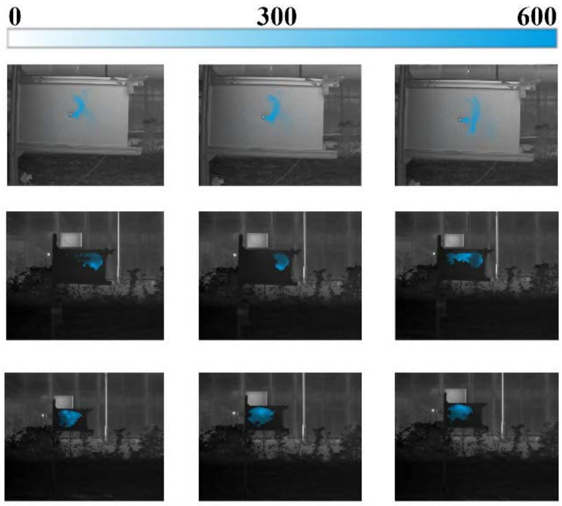

Figure 4 Exemplary frames of methane cloud quantifications, measured with the active gas camera at distances - from top to bottom: 2m, 5m and 7m at a flow of 40 ml/min. The concentration is given in ppm*m. The grey values indicate the measured infrared radiation.

3 Summary and outlook

A setup and method for a real time methane visualization based on a three-image concentration calculation is realized. At a flow of 40 ml/min, methane leaks can clearly be quantified and gas leakages identified. Based on this data, further post processing steps are possible to gain additionally information. One example may be the sensor fusion with visible and depth data, to increase comprehensibility as well as to correct the measured leak concentrations by the environmental methane.
Furthermore, the practical use of the active approach is to be proven on poorly reflecting backgrounds. An approach that holds this potential could be a "methane laser scanner" that may increase the signal to noise significantly by using a focused laser beam that is rasterized over the field of view. In such a scenario, eye safety could become the limiting factor.

4 Literature

[1] E. G. Nisbet *et al.*, "Very Strong Atmospheric Methane Growth in the 4 Years 2014–2017: Implications for the Paris Agreement," *Glob. Biogeochem. Cycles*, vol. 33, no. 3, pp. 318–342, 2019
[2] K. J. Nutt, N. Hempler, G. T. Maker, G. P. A. Malcolm, M. J. Padgett, and G. M. Gibson, "Developing a portable gas imaging camera using highly tunable active-illumination and computer vision," *Opt. Express*, vol. 28, no. 13, p. 18566, Jun. 2020
[3] T. Strahl, J. Herbst, A. Lambrecht, E. Maier, J. Steinebrunner, and J. Woellenstein, "Methane leak detection by tunable laserspectroscopy and mid-infrared imaging," *Appl. Opt.*, Mar. 2021