Ultra-broadband infrared gas sensor for pollution detection

TRIAGE

TRIAGE project newsletter #3

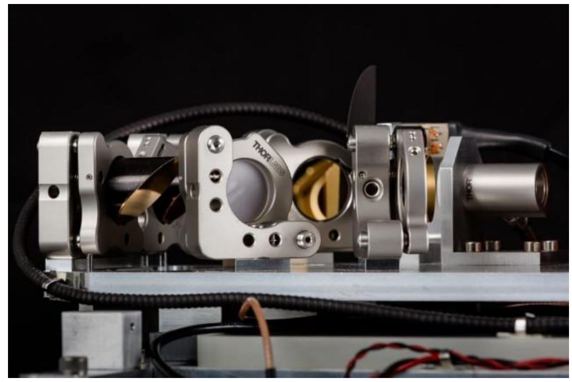
Oct-2022

This project has received funding from Horizon 2020, the European Union's Framework Programme for Research and Innovation, under Grant Agreement No. 101015825.

Welcome to the third TRIAGE project newsletter!

Work is progressing well in TRIAGE! In this newsletter we report on the following TRIAGE topics from recent months:

- Characterising end-user test sites at LiU
- Plasma analysis using TRIAGE methods at RU
- 2 µm pump development at NKT Photonics
- Online TRIAGE machine learning-based gas spectroscopy demonstrator from CSEM
- ECREAM booth at Photonics Europe 2022.



More information is available on the project website https://triage-project.info

Characterising end-user test sites for TRIAGE validation

LINKÖPING UNIVERSITY

Awaiting delivery of the first TRIAGE prototype for testing, the LiU team has characterised gas emissions from end-user test sites with available equipment (Fig. 1) which targets fewer gases than the planned TRIAGE system. Figures 2 and 3 show examples from a sewage water treatment plant and a biogas production plant in collaboration with a TRIAGE-NET partner (Tekniska Verken, Linköping). These tests are helpful to learn about spatial and temporal patterns of gas releases from different parts of the plants.

Fig. 1: Showing the equipment used to gather the data on characterised gas emissions from end-user test sites. For more info see M. Gålfalk et al. https://doi.org/10.1016/j.envres.2021.111978

Consortium

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PHOTONICS[21] PHOTONICS PUBLIC PRIVATE PARTNERSHIP

TRIAGE is an initiative of the Photonics Public Private Partnership.

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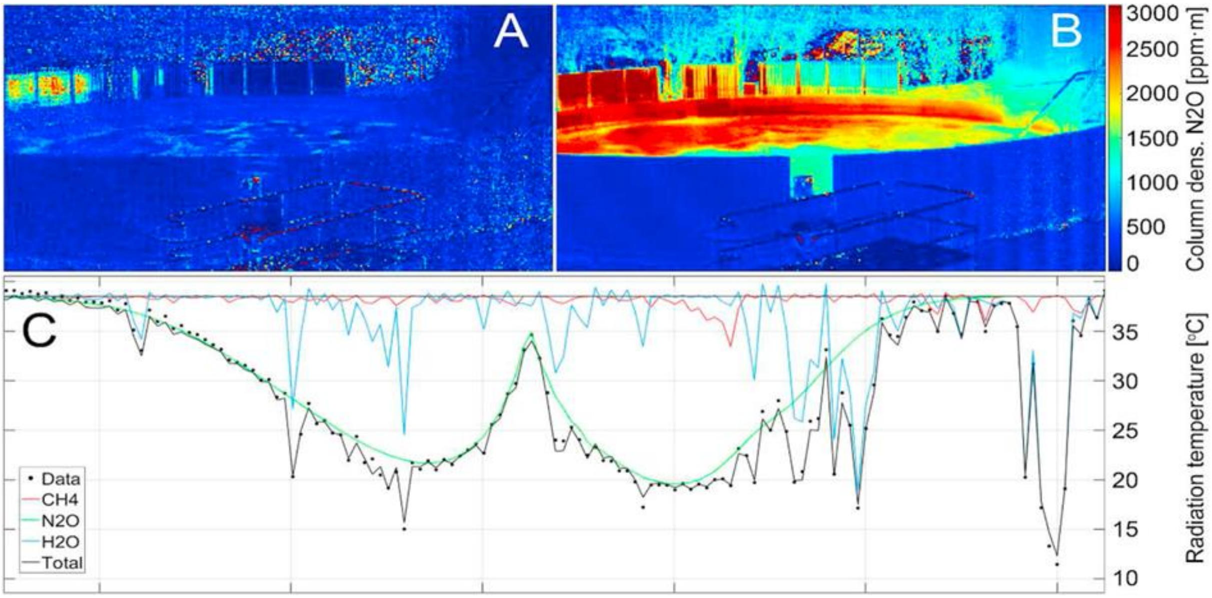

Fig. 2: Maps of nitrous oxide (N_2O) above one of the treatment dams in a sewage treatment plant during non-aeration (A) and aeration (B) periods and an example spectrum with fitted models of CH_4, N_2O, H_2O, and total absorption for a line of sight from a hyperspectral sensor during high emissions (C).
For details, see Gålfalk et al. *(2022), below.*

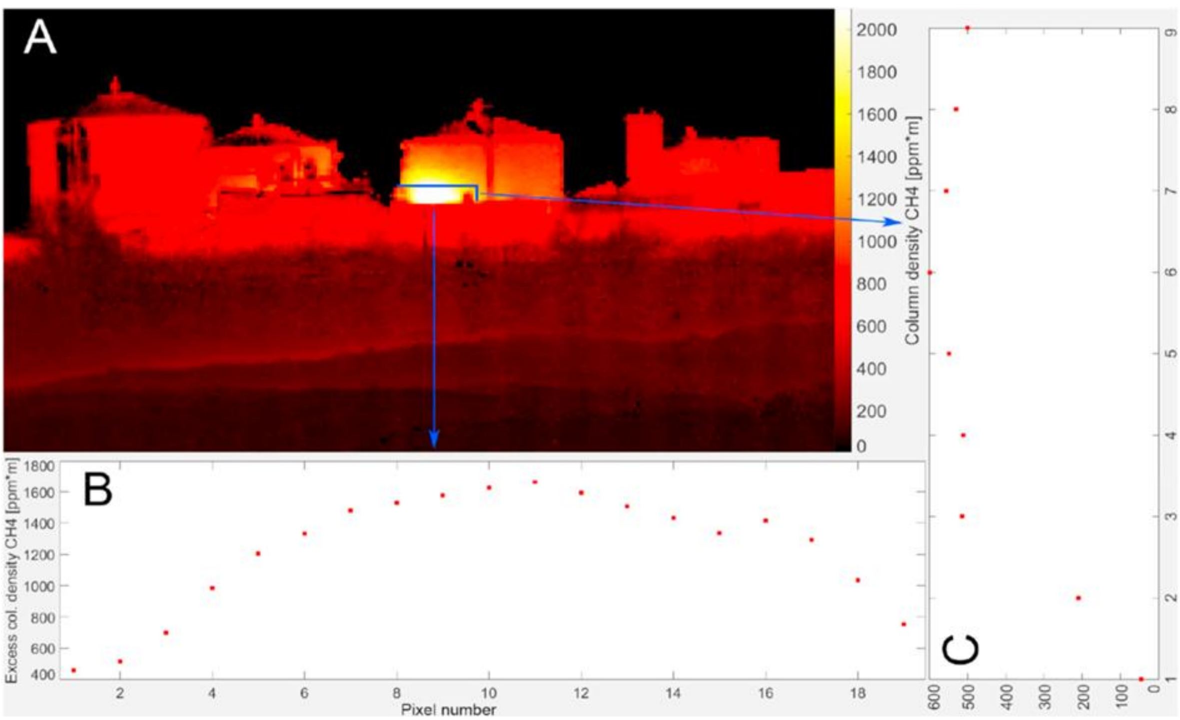

Fig. 3: Methane (CH_4) column densities in an overview of a biogas plant showing a location vulnerable for leakage (A), combined with vertical (B) and horizontal (C) flux profiles along the blue lines.
For details, see Gålfalk et al. (2022), below.

This work was recently published in the scientific journal Environmental Research:

Ground-based remote sensing of CH_4 and N_2O fluxes from a wastewater treatment plant and nearby biogas production with discoveries of unexpected sources

Gålfalk M, Påledal SN, Sehlén R, Bastviken D.

Env. Res. **204**, 111978 (2022). https://doi.org/10.1016/j.envres.2021.111978

Plasma analysis by the prototype TRIAGE sensor at RU

Radboud University

The prototype TRIAGE sensor developed at Radboud University demonstrates great potential for multi-species detection in various real-life scenarios. One of the interesting applications is in the analysis of plasma-based gas conversion processes, in which the TRIAGE sensor can be used to detect (almost) all of the reactants and products simultaneously. This provides a unique opportunity to fully analyse the conversion process in real-time and maximise its efficiency for producing the target gas species.

One interesting process is the conversion of two common greenhouse gases, carbon dioxide (CO_2) and methane (CH_4), into carbon monoxide (CO) and hydrogen (H_2), also known as syngas. Although traditional (catalytic) pyrolysis and dry reforming methods are considered efficient ways to produce syngas and oxygenates from CO_2 and CH_4, high temperatures and pressures are usually required. To meet these requirements, the energy is largely supplied by burning fossil fuels, which is therefore accompanied by high CO_2 emissions. Compared with thermal methods, (discharge) plasmas can be powered by fully-sustainable green energy, avoiding CO_2 release. However, the plasmas formed in electric discharges are complex systems, consisting of numerous (reactive) species, and it is a challenge to control the reaction specificity.

The RU researchers utilised the TRIAGE sensor for the detection of reactants and products of plasma-based gas conversion in an electrical discharge tube as shown in Figure 4.

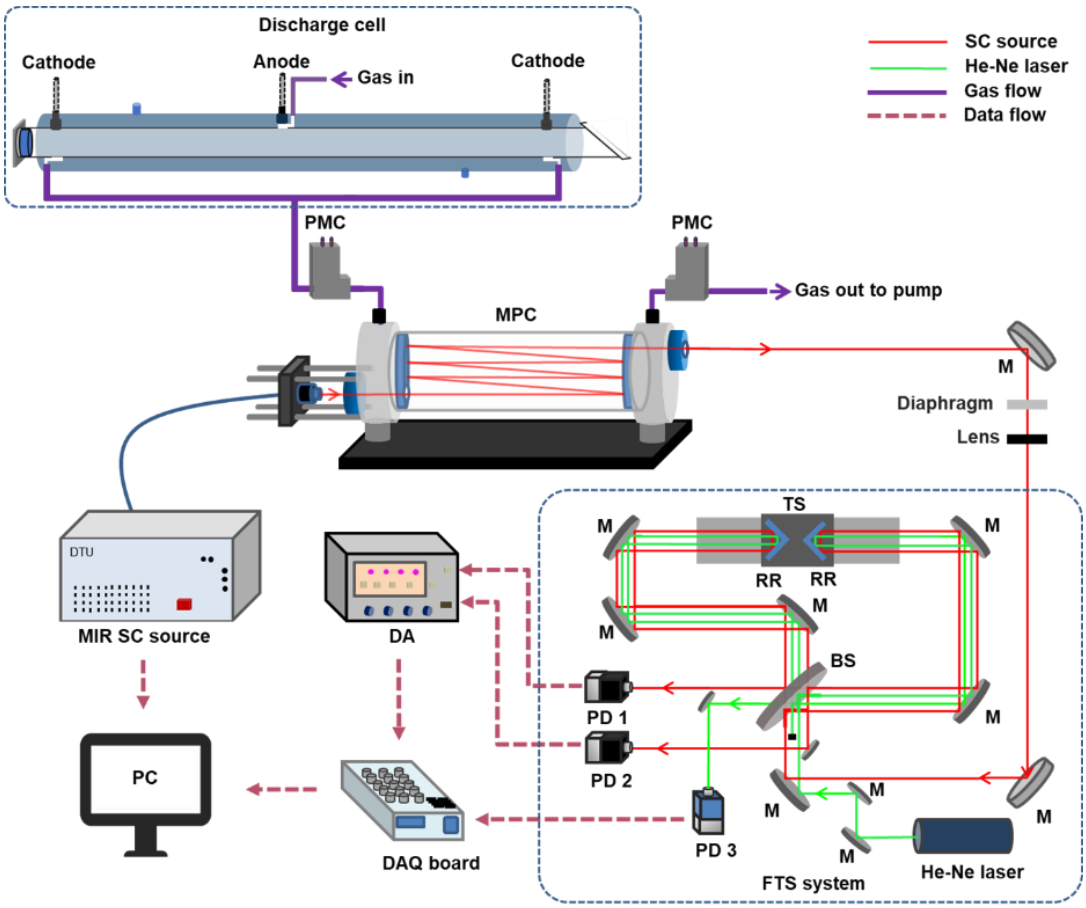

Fig. 4: Experimental set-up of plasma study using the TRIAGE sensor.

MPC: Multipass cell

PMC: Pressure meter & controller,

M: Mirror

TS: Translation Stage

RR: Retroreflector mirror

BS: Beamsplitter,

He-Ne laser: Helium-Neon laser

PD: Photodetector

DA: Differential Amplifier

DAQ board: Data Acquisition board

PC: Computer.

In this configuration the gas outflow of a discharge plasma reactor is sent to a multi-pass absorption cell, monitored by the TRIAGE prototype sensor. Two different gas mixtures were used as the reactants; 50 % CO_2/50 % N_2 and 70 % CH_4/30 % CO_2. The measurement results of the spectrum of the gas mixture in the outflow are shown in Figure 5.

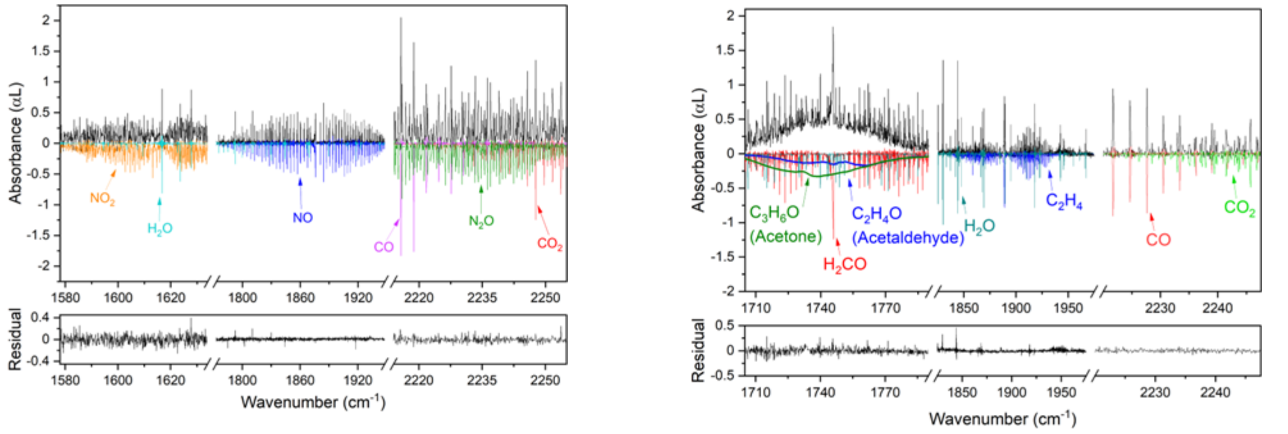

Fig. 5: (a) Measured spectrum (in black) of reaction products of a 50 % CO_2/50 % N_2 discharge and the fitted modelled spectra (in colours, inverted) based on the HITRAN database parameters. (b) Measured spectrum (in black) of reaction products of a discharge of 70 % CH_4/30 % CO_2 (in black). In colour are the fitted reference spectra of formaldehyde, water, carbon monoxide, carbon dioxide (from HITRAN), acetone and acetaldehyde (from PNNL) and ethylene (from GEISA) shown inverted. The residual of the fits are shown in the lower panels.

The flat and featureless residuals show a very good match between the model and the measured spectra. Table 1 shows the concentrations of different gases retrieved from the fits.

Table 1. Retrieved concentrations of electric discharge products.

	Retrieved concentration (% or ppm)	
	50% CO_2/50% N_2	30% CO_2/70% CH_4
Carbon dioxide (CO_2)	13.0 ± 0.6 %	13.9 ± 0.7 %
Carbon monoxide (CO)	14.6 ± 0.7 %	32.1 ± 1.7 %
Nitrous oxide (N_2O)	570 ± 30 ppm	--
Nitrogen dioxide (NO_2)	154 ± 13 ppm	--
Nitric oxide (NO)	0.33 ± 0.01 %	--
Ethylene (C_2H_4)	--	0.73 ± 0.03 %
Formaldehyde (H_2CO)	--	0.13 ± 0.01 %
Acetone (C_3H_6O)	--	0.3 ± 0.1 %
Acetaldehyde (C_2H_4O)	--	0.3 ± 0.1 %

The successful simultaneous measurement of the reaction products with very different concentration levels and molecular sizes, proves the effectiveness of the TRIAGE sensor for plasma study. More information can be found in a recent RU publication on this topic:

Mid-infrared supercontinuum-based Fourier transform spectroscopy for plasma analysis

R. Krebbers, N. Liu, K. E. Jahromi, M. Nematollahi, O. Bang, G. Woyessa, C. R. Petersen, G. van Rooij, F. J. M. Harren, A. Khodabakhsh and S. M. Cristescu,

Sci. Rep. **12**, 9642 (2022). https://doi.org/10.1038/s41598-022-13787-w

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2 µm pump development for MIR supercontinuum generation at NKT Photonics

To generate a broadband mid-infrared (MIR) source for air-pollution detection, the role of NKT Photonics (NKTP) in TRIAGE is to develop a high power 2 µm fibre pump laser that enables effective MIR supercontinuum (SC) generation spanning from 2-10 µm with DTU's chalcogenide glass fibres and Norblis' SC technology. In MIR SC generation, the method of SC cascading is often adopted due to easy handling and robust and compact all-fibre design. When initiating spectral broadening, a pump source is launched into the ZBLAN fibre to broaden its spectrum up to ~4.0 µm. The pump source should have a wavelength longer than 1.6 µm (the zero-dispersion wavelength of ZBLAN fibre) to allow SC generation in the anomalous dispersion regime. Current commercial 2 µm pumps are based on the mature technology of an Er/Yb master-oscillator power amplification (MOPA), plus a length of single mode fibre (SMF) and/or Tm-doped SMF to shift the pump wavelength above 2 µm. However, these additional fibres not only add to the complexity, but the nonlinear effects they introduce significantly limit the power scaling. In contrast, direct generation of the 2 µm pump permits more efficient SC generation and guarantees more power scaling. This is NKTP's target in this project.

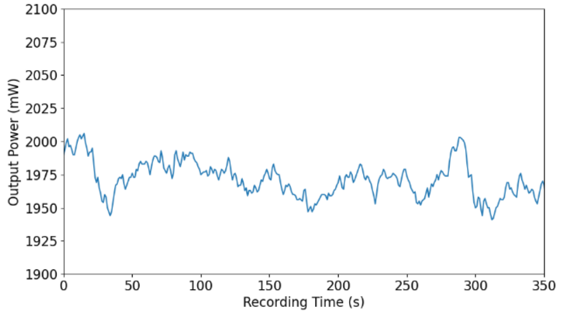

Figure 6: Output power of NKTP 2 µm MOPA.

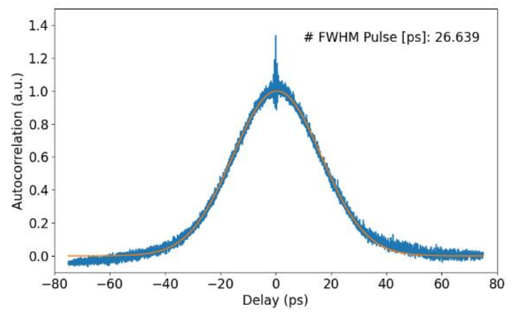

Figure 7: Autocorrelation trace of 2 µm MOPA.

NKTP's 2 µm pump is based on the amplification chain after a gain-switched seed laser (NKP product: PILAS) at 1970 nm. PILAS can deliver a <100 ps pulse train and has a continuously tunable pulse repetition rate (up to 40 MHz). The seed laser itself has a rather low average power (~500 nW at 3 MHz) and thus requires high gain and low noise in the subsequent amplification. Such amplifiers are difficult to find in the commercial market, but NKTP has the expertise to provide a high power 1.5 µm continuous wave (CW) laser with SMF output as the seed pump to secure sufficient signal amplification. At 3 MHz, the source achieved ~2 W average power (Figure 6) and ~30 ps pulse duration (Figure 7), corresponding to over 22 kW peak power, and development continues!

For more info contact Dung-Han Yeh: dung-han.yeh@nktphotonics.com

TRIAGE machine learning-based gas spectroscopy demonstrator: now online at https://triage.tk

Traditionally, to find the composition and amount of gas in a sample, one compares the measured absorption spectrum with the one stored in a database (*e.g.* HITRAN) by using a least square fitting algorithm. TRIAGE aims to implement such analysis using machine learning algorithms, as they are potentially faster and more robust for mixtures of different gases. As hinted by the name, machine learning algorithms need to be trained. This has been done by feeding the algorithms with large number of artificially generated absorption spectra. These were produced initially with data from the HITRAN database and then by varying some of the parameters including gas concentration, noise level, baseline shape *etc*. in order to mimic real spectra recorded by a spectrometer. A first demonstrator with five greenhouse gases (methane, carbon dioxide, water vapour, nitrous oxide, and ozone) has been developed for use on a laptop for showing at international fairs.

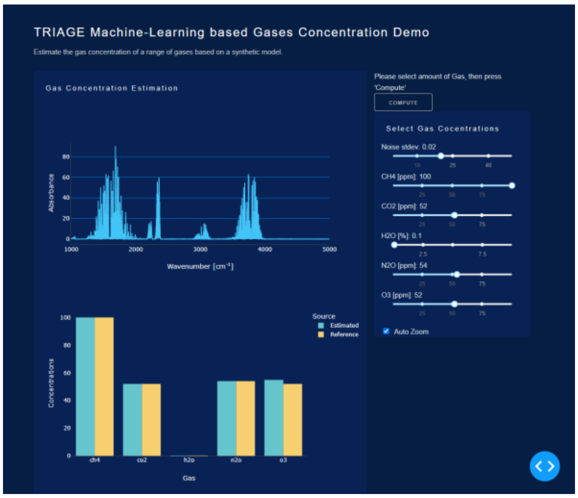

Figure 8: Screenshot from the CSEM demo.

For more info contact Laurent Balet:
laurent.balet@csem.ch

Today, CSEM is proud to announce that the machine learning models have been ported to the cloud and are accessible to a much broader audience at the address https://triage.tk/. There, the interested user can set a mixture of those five gases and, by pressing the compute button, generate the absorption spectrum of the mixture and launch the machine learning algorithm on this spectrum. A bar graph shows how well the algorithm performed in retrieving the set concentrations.

Have fun playing this demo!

ECREAM at Photonics Europe 2022

Six projects from ECREAM (European Cluster of Research projects for Environmental and Agri-food Monitoring) shared booth #227 at Photonics Europe in Strasbourg, France (05-06 Apr-2022). The event also featured conference sessions from 03-07 Apr-2022.

Members of the following projects were on the booth to present the latest results and answer any questions on the work:

AEOLUS	PHOTONFOOD
GRACED	TRIAGE
h-ALO	ULISSES

A number of interesting links were made during the conference, and several new potential applications and industrial areas were identified for collaboration.

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ECREAM
European Cluster of Research projects for Environmental and Agri-food Monitoring

More information can be found on the TRIAGE ECREAM webpage:
https://triage-project.info/links/ecream