What is Nexus ExposUM ?

The Doctoral Nexus proposed by l'Institut ExposUM are networks of 3 to 4 PhD students from different disciplines, affiliated to at least two different research units.

Compared with a conventional thesis, participation in a Doctoral Nexus will foster the ability to work in a team and design projects in a transdisciplinary way, while deepening one's own field of expertise.

A specific pedagogical program will be offered, and doctoral students will also have the opportunity to organize a seminar within the Nexus network.

Thesis are funded for 4 years, including the doctoral student's salary and an environmental allowance.

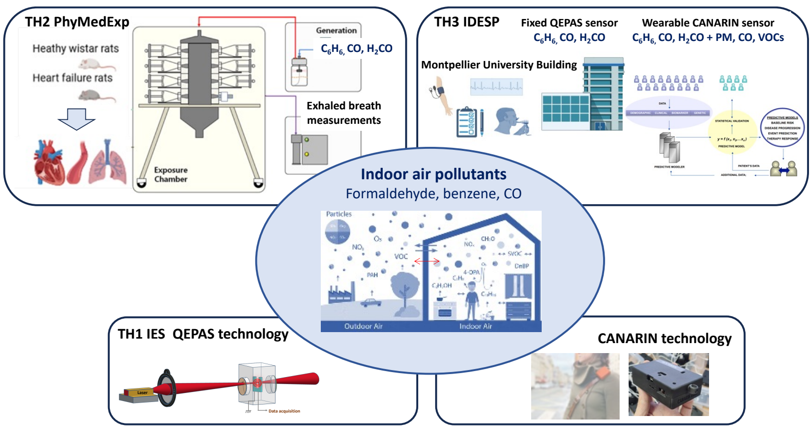
Thesis subject : Development of photoacoustic sensors to assess pollutant environment and exhaled breath pollutant exposure (C_6H_6, H_2CO, CO)

Part of Project NEXUS 2024 EXPAIR (Development of innovative sensors for measuring EXPosure to pollutants in AIR to unravel cardiorespiratory effects)- Transdisciplinary collaboration between Electronics Institute (IES) and two medical research laboratories.

Supervisors : VICET Aurore (MCF HDR), BAHRIZ Michael

Location: IES UMR CNRS 5214, Campus St Priest, Montpellier, France

Context



The World Health Organization evaluates that air pollution kills 13 people every minute **all around the world. This pollution concerns outdoor and indoor exposition. Some pollutants can be found mainly outside (CO, NOx, particles...) but others (Benzene, formaldehyde...) are mainly produced inside our homes, offices, companies.**

Indoor pollution exposition is poorly characterized, and a strong demand from public organisms is expressed to make available exposition sensors of unregulated species.

The aim of EXPAIR project is to provide some measurement tools of air quality and pollutant expositions (collective and individual) and use them to understand the phenomena involved in the appearance of human pathologies during short- and long-term exposure.

This project is multidisciplinary in nature, aiming to advance the development of innovative sensors utilizing Quartz-Enhanced Photoacoustic Spectroscopy (QEPAS) technology. Simultaneously, it seeks to deploy an affordable wearable device known as CANARIN for the purpose of conducting high-resolution measurements of environmental and individual parameters, specifically targeting indoor pollutants such as formaldehyde (H2CO), benzene (C_6H_6), and carbon monoxide (CO). The overarching goal is to evaluate the impact of these pollutants on cardiorespiratory health.

Three thesis are affiliated with IES, PHYMEDEXP and IDESP. The objectives of each thesis are as follows:

Thesis 1 TH1 – **This proposal**) To fabricate sensitive sensors utilizing photoacoustic sensing techniques for the detection of CO, C_6H_6 and H_2CO in ambient air monitoring and exhaled breath analysis (This proposal)
Thesis 2 TH2) To investigate the influence of the internal exposome, assessed through exhaled breath sensing, on cardiovascular systems during chronic exposure
Thesis 3 TH3) To analyze the effects of pollutant doses on respiratory health under real- life conditions

Thesis TH1 description

Photoacoustic (PA) sensing is a highly selective and sensitive method for detecting traces of gas in a gaseous mixture. It uses an infrared laser whose wavelength is absorbed by a spectrally fine absorption line of the target molecule (ro-vibrational transitions), making the method extremely selective. The modulated absorption gives rise to an acoustic wave which, when detected by a mechanical resonator (quartz tuning fork = QTF, very inexpensive commercial piezoelectric mechanical resonator), gives rise to the QEPAS **(Quartz Enhanced Photoacoustic Spectroscopy [Kosterev 02])** measurement technique.

While all laser spectroscopy methods (direct detection, resonant cavities, etc.) offer this selectivity, only PA allows to work on very small volumes, since the signal intensity is linked not to the length of the equivalent optical path absorbed, but to the light power deposited and absorbed in the vicinity of the resonator. On the other hand, measurement in the acoustic domain eliminates the need for photodetectors adapted to the wavelength of the laser source: the detector (acoustic transducer) remains the same whatever the working wavelength.

QEPAS has demonstrated in IES excellent detection levels on numerous molecules in a wide range of applications [Jahjah 12] [Triki 15] [Rousseau 19] [Maurin 20] [Ayache 22], at the international state of the art. They are based on an off-beam configuration using a tiny resonant acoustic cell to increase coupling between the generated acoustic wave and the QTF [Rousseau 19]. Compared with non-optical methods such as physico-chemical, metal oxide, flame ionization or plasmonic sensors, which can give very good sensitivities, the use of tunable lasers gives QEPAS a perfect selectivity that sets it apart from competitors. This selectivity is indispensable for any measurement requiring the ability to discriminate one species from another, and to give its exact concentration.

We propose to develop two types of sensors which will be used in thesis n°2 and n°3. One gas monitoring station in ambient air for on-site pollution measurements, the other for exhaled breath monitoring to analyze the cardiovascular effect of exposure to pollution. **These two sensors will rely**

on IES's experience in the field of gas sensors and will strive to push back the limits of detection and measurement systematization demonstrated to date.

Objectives :

Photoacoustic measurement techniques can be used for a wide variety of applications, by adapting the setups around a common concept.

The subject of the proposed thesis is articulated around 2 axes:

- Development of ambient air sensors, assessment of exposure to pollutants: formaldehyde, Benzene, and CO. This type of sensor will be optimized in the laboratory and positioned at chosen strategic sites for 2 weeks measurement campaigns carried out during thesis 3.
- Development of exhaled breath sensors for physiological analysis of pollutant levels in respiratory compartments, application to animal model. Determination of alveolar versus bronchial and dead space production. Potential application to CO, NO, isoprene, acetone, benzene. These sensors will be used in thesis n°2 to analyze exhaled breath in the animal model.

Methods :

If the results given by previously published PA sensors allow us to envisage good level of measurements, we plan to improve their performances on several levels. The basic principle of PA measurement using an acoustic resonator remains the same, but it will be enhanced:

- Working on the addition of a multi-pass acoustic cell to the optical setup: while maintaining fast measurements (1<s), we will work on an optical multi-pass PA approach, which will locally increase the light density provided near the resonator. This technique requires a new optical design for the measurement. The design of the multipass cell will be carried out in the laboratory and will be inspired by flat designs [Manninen 12]. Because of reflection losses on the mirrors, the increase in PA signal is not directly proportional to the number of round trips [Saarela 10], and we estimate a minimum gain of a factor of 10 on the focused power. This cell will be acoustically resonant at the transducer's resonant frequency, to increase acoustic coupling. Quality factors of over 150 have been reported [Manninen 12]. As a result, compared with QEPAS off-beam configurations, a **total gain of more than a factor of 50 can be achieved on previously published detection limits.**

- For measurements of exhaled breath, the coupling of photoacoustic optical devices to respiratory sampling equipment from MEDISOFT has been studied as part of the SENSIR project [Ayache 23][Maurin 20]. This equipment enables rapid recording of expirograms: respiratory flows, volumes, capnography and simultaneous measurement of a gaseous species of cardiovascular interest (CO, NO, acetone, isoprene). The work on this equipment will focus on simultaneous multi-gas measurements, the addition of benzene and the improvement of limit of detection on acetone and NO, and the adaptation of the device to the animal model within the framework of thesis n°2.

The PhD student will work on each aspect of the device, from optical optimization in the infrared range, to instrumentation, data acquisition and processing. He/she will be required to implement devices in collaboration with physiology and clinical research laboratory teams. He will be supervised mainly by

Aurore VICET and Michel BAHRIZ (IES), and will work closely with Fares GOUZI (PHYMEDEXP) and Luciana KAZE TANNO (IDESP).

References

[Ayache 22] [Ayache 22] Ayache, Diba, et al. "Benzene sensing by quartz enhanced photoacoustic spectroscopy at 14.85 µm." Optics Express 30.4 (2022): 5531-5539.

[Jahjah 12] [Jahjah 12] M. Jahjah, A. Vicet and Y. Rouillard. A QEPAS based methane sensor with a 2.35 µm antimonide laser Applied Phys B. Volume 106, Number 2, Pages 483-489, 2012.

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[Manninen 12] [Manninen 12] A. Manninen, B. Tuzson, H. Looser, Y. Bonetti, and L. Emmenegger. 2012. Versatile multipass cell for laser spectroscopic trace gas analysis. Appl. Phys. B 109, 3, 461–466. DOI: https://doi.org/10.1007/s00340-012-4964-2.

[Maurin 20] [Maurin 20] N. Maurin, R. Rousseau, W. Trzpil, G. Aoust, M. Hayot, J. Mercier, M. Bahriz, F. Gouzi And A. Vicet First clinical evaluation of a quartz enhanced photo-acoustic CO sensor for human breath analysis. Sensors and actuators (319) 128247 (2020). https://doi.org/10.1016/j.snb.2020.128247

[Rousseau 19] [Rousseau 19] Roman Rousseau, Zeineb Loghmari, Michael Bahriz, Kaim Chamassi, Roland Teissier, Alexei N. Baranov and Aurore Vicet Off-beam QEPAS sensor using a 11µm DFB-QCL with an optimized acoustic resonator - Optics Express 27 (5) 7435-7446, 2019. https://doi.org/10.1364/OE.27.007435.

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[Triki 15] [Triki 15] M. Triki , T. Nguyen Ba and A. Vicet, Compact sensor for methane detection in the mid infrared region based on Quartz Enhanced Photoacoustic spectroscopy, Infrared Phys. Technol, 69 pp 74-80 2015

Duration of the thesis : 4 years

Formation expected :

Engineer Diploma, Master 2 or equivalent grade in General physics, optics, optoelectronics.

Skills :

- Applied physics : optics, optoélectronics, lasers, semiconductors, spectroscopy, electronics
- Computering : programmation (Python, C…) , instrumentation, modelisation (ray tracing, finite elements…)
- Autonomy, scientific rigor, organization, project management, ability to synthetise, writing and presentation skills
- English level B2-C1 minimum
-

How to apply :

Please send :

- A CV
- A motivation letter
- A copy of the diploma allowing the application
- Specific elements asked by the doctoral school : (https://edi2s.umontpellier.fr/)

email to :

aurore.vicet@umontpellier.fr and exposum-aap@umontpellier.fr

Before Sunday 21TH April 2024, 20h CET

The University of Montpellier

KEY FIGURES

- **52372** students
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