UMR Acoustique Environnementale

Environmental Acoustics Research Laboratory

(Université Gustave Eiffel-Cerema)

PhD Thesis proposal 2024

Title

Application of metamaterials to reduce environmental noise

Formation

☒Research master degree (M2) or equivalent

Required skills

Main Disciplines: Acoustics, Physics, Materials

Description

The Environmental Acoustics research unit (UMRAE) develops research in order to offer a better control of noise pollution and, to improve the quality of sound environments. Among the UMRAE's objectives, the development of noise reduction techniques is a concrete response to a strong societal demand. The development of low noise pavements or optimized noise screens, the use of absorbent materials... remain the basis of the proposed solutions, but are still based on "classic" concepts. The improvement of noise reduction systems must now change paradigm to meet the challenges at hand. Thus, the development of innovative solutions based on acoustic metamaterials is an avenue of research to explore. Metamaterials are artificial media whose structure generates specific properties, for example by controlling the propagation of waves in the air. The interest of these materials in the environmental field has been very little developed and few scientific results have been published [1,3,7].

Acoustic metamaterials offer the possibility to tailor the temporal dispersion of waves and to control the spatial propagation of sound waves. Acoustic barriers based on sonic crystals are one of the first known applications of metamaterials [10]. They are used to control noise in road traffic, to limit noise on fixed and mobile construction sites, and more generally in all noisy activities where it is not possible to control the noise propagation [4]. Nowadays, the construction of noise barriers using metamaterials is a common practice [9]. Recent papers also showed that the combination of vegetation and metamaterials can also be a solution to reduce road traffic noise [5,11].

However, a metamaterial is difficult to adapt to other phenomena once it has been created for a specific wave control target with defined geometric parameters. Their design is based on the assembly of several fixed components, which makes them inflexible and not continuously adjustable. To overcome this limitation, more attention has been paid to dynamic acoustic metamaterials. Reconfigurable metamaterials can achieve continuously adjustable sound absorption at a thickness in the sub-wavelength range [6]. In terms of their numerous technical applications, they have important advantages over their static counterparts. In situations where the acoustic environment changes, they can be tuned to adapt to the surrounding conditions.

Thus, the objective of the thesis work will be to propose principles of metamaterials-based solutions which could be implemented within the framework of the reduction of the noise annoyance, applied to the reduction of the acoustic emission (action on the source) or to the protection of the inhabitants/passers-by. A specific attention will be paid to reconfigurable metamaterials that can offer very innovative perspectives.

The work will require the realization of a bibliographic study on acoustic metamaterials, the description of the environmental noise problem (and of the standard solutions), and the proposal of possible innovative solutions based on acoustic metamaterials. The student will identify one or more solutions that will be tested, for example by measurements, thanks to the realization of a real scale prototype or at a scale model, and/or by the realization of numerical simulations. These solutions will be compared to conventional noise reduction solutions that are considered as equivalent. Concerning the realization of numerical simulations, it will be necessary to identify the most appropriate numerical methods adapted to the problem (frequency/time methods), in particular among those available within the UMRAE. If necessary, it will require to develop a specific calculation code or to use commercial numerical tools.

The student will have at his disposal the testing facilities and the numerical simulation tools available within the UMRAE laboratory, as well as the expertise in environmental acoustics of Judicaël Picaut (PhD supervisor, UMRAE, Université Gustave Eiffel) and in acoustic metamaterials of Rubén Picó Vila (co-supervisor, Universitat Politècnica de València). Depending on the evolution of the thesis, additional expertise may be sought.

References:

1. Cop, Philipp, John Nguyen, et Brady Peters. 2023. « Modelling and Simulation of Acoustic Metamaterials for Architectural Application ». In *Towards Radical Regeneration*, édité par C. Gengnagel, O. Baverel, G. Betti, M. Popescu, M. R. Thomsen, et J. Wurm, 223-36. Cham: Springer International Publishing Ag. https://doi.org/10.1007/978-3-031-13249-0_19.
2. Duan, Mingyu, Chenlei Yu, Wei He, Fengxian Xin, et Tian Jian Lu. 2021. « Perfect sound absorption of Helmholtz resonators with embedded channels in petal shape ». *Journal of Applied Physics* 130 (13): 135102. https://doi.org/10.1063/5.0064811.
3. Kumar, Sanjay, et Heow Pueh Lee. 2019. « The Present and Future Role of Acoustic Metamaterials for Architectural and Urban Noise Mitigations ». *Acoustics* 1 (3): 590-607. https://doi.org/10.3390/acoustics1030035.
4. Lannace, Gino, Giuseppe Ciaburro, et Amelia Trematerra. 2021. « Metamaterials Acoustic Barrier ». *Applied Acoustics* 181 (octobre): 108172. https://doi.org/10.1016/j.apacoust.2021.108172.
5. Lau, Siu-Kit, Xing-Feng Zhu, et Zhenbo Lu. 2021. « Enhancing the Acoustic Absorption of Vegetation with Embedded Periodic Metamaterials ». *Applied Acoustics* 171 (janvier): 107576. https://doi.org/10.1016/j.apacoust.2020.107576.
6. Liu, Hongxing, Jiu Hui Wu, et Fuyin Ma. 2021. « Dynamic Tunable Acoustic Metasurface with Continuously Perfect Sound Absorption ». *Journal of Physics D: Applied Physics* 54 (36): 365105. https://doi.org/10.1088/1361-6463/ac0ab9.
7. Lu, Qiangbing, Xin Li, Xiujuan Zhang, Minghui Lu, et Yanfeng Chen. 2022. « Perspective: Acoustic Metamaterials in Future Engineering ». *Engineering* 17 (octobre): 22-30. https://doi.org/10.1016/j.eng.2022.04.020.
8. Peng, Yao-Yin, Zhang-Zhao Yang, Zhi-Lei Zhang, Xin-Ye Zou, Chao Tao, et Jian-Chun Cheng. 2022. « Tunable acoustic metasurface based on tunable piezoelectric composite structure ». *The Journal of the Acoustical Society of America* 151 (2): 838-45. https://doi.org/10.1121/10.0009379.
9. Redondo, Javier, Pau Gaja-Silvestre, Luis Godinho, et Paulo Amado-Mendes. 2022. « A Simple Method to Estimate the In Situ Performance of Noise Barriers ». *Applied Sciences* 12 (14): 7027. https://doi.org/10.3390/app12147027.
10. Sanchez-Perez, Juan V., Constanza Rubio, Rosa Martinez-Sala, Rafael Sanchez-Grandia, et Vicente Gomez. 2002. « Acoustic barriers based on periodic arrays of scatterers ». *Applied Physics Letters* 81 (27): 5240-42. https://doi.org/10.1063/1.1533112.
11. Zhu, Xing-Feng, Siu-Kit Lau, Zhenbo Lu, et Lai Fern Ow. 2020. « Enhancement of Sound Absorption via Vegetation with a Metasurface Substrate ». *Applied Acoustics* 165 (août): 107309. https://doi.org/10.1016/j.apacoust.2020.107309.

Doctorate school

The student will be enrolled in the “Engineering and Systems Sciences” Doctoral School (SIS, Sciences de l'Ingénierie et des Systèmes) (https://ed-sis.doctorat-paysdelaloire.fr/).

Thesis location

The thesis will take place at the Campus of Nantes, Université Gustave Eiffel. Travels are also planned over the duration of the thesis (training, conferences, summer school, visits in other laboratories…).

Thesis direction

Supervisor: Judicaël Picaut (UMRAE), Senior Researcher
Co- Supervisor: Rubén Picó Vila, Professor, Universitat Politècnica de València

Fundings

Université Gustave Eiffel fundings subject to selection of the candidate by the “Engineering and Systems Sciences” Doctoral School audition committee.

Additional information

- UMRAE website : https://www.umrae.fr/

Contacts

M. Judicaël PICAUT (UMRAE)
Tel. +33 2 40 84 57 89
Email: Judicael.Picaut@univ-eiffel.fr