

Explainable and Physics-Informed AI for the Development of Smart THz Sensors Dedicated to Industry, Environment, Healthcare and Energy Transition

Scientific context

The reliability of automated systems relies on the quality of the data provided by sensors. In many strategic sectors such as industry, healthcare, energy, or the environment, sensors constitute the primary source of information used for decision-making, process control, or diagnostic support. Artificial intelligence (AI) is now widely used to improve the processing, interpretation, and automation of these data. However, current approaches are predominantly based on “black-box” models, whose decisions are difficult to interpret and which can sometimes lack robustness when faced with new or degraded experimental conditions. In critical domains, the trust placed in these systems requires strong properties of robustness, repeatability, adaptability, and explainability. One of the main scientific challenges is therefore to develop a new generation of AI algorithms capable of explicitly incorporating the physical laws governing the observed phenomena.

The present PhD research, both fundamental and application-oriented, will be carried out with the support of company PARSEWAVES within the framework of a CIFRE agreement. This partnership will enable joint fundamental and methodological research on the integration of physical knowledge into AI models and the deployment of an innovative technology, while confronting their development with challenges and data arising from concrete industrial applications. The collaboration with PARSEWAVES will thus help orient the research towards application-related scientific and technological challenges identified by the company, while enabling the experimental validation of the methods developed under conditions representative of their future use. This close interaction between PARSEWAVES and the partner laboratories will also foster scientific excellence, notably through the dissemination of results in international conferences and scientific journals, as well as the transfer of the knowledge and technologies developed to the company, in particular through the protection and valorization of innovative results potentially leading to patent applications.

PhD objectives

This PhD thesis aims to develop **Physics-Informed AI** methods in order to design smart sensors capable of:

- exploiting known physical laws during the learning process;
- improving the robustness and generalizability of the models;
- explaining the decisions made by the algorithm;
- automatically detecting measurement errors or abnormal situations;
- improving the understanding of the underlying physical phenomena.

The main objective is to propose explainable AI architectures capable not only of extracting relevant information from measurements, but also of assisting the user in the physical interpretation of the results.

Application domain: THz sensors and imaging

Terahertz (THz) waves occupy an intermediate position between microwaves and infrared radiation. They exhibit properties that are particularly interesting for the non-destructive analysis of materials [1]:

- penetration through many dielectric materials [2];
- multilayer thickness measurement [3];
- moisture detection [4];
- characterization of materials and internal defects [1], [2];
- contactless imaging without ionizing radiation [5].

These technologies are now finding applications in Industry 4.0 and 5.0, quality control and non-destructive testing, future telecommunications [6], security [5], the agri-food sector [7], the pharmaceutical sector [8], healthcare and biomedical applications [9], and environmental monitoring [10].

The thesis will focus more specifically on a topic with strong societal impact: **the energy diagnosis of buildings**.

THz systems can indeed be used to assess the condition of insulating materials through the structural materials that make up walls, detect the presence of moisture, identify hidden defects or delaminations, and monitor the ageing of structures. This information is essential for quantitatively assessing the energy performance of the building stock and thus effectively supporting energy transition objectives.

Scientific challenges

Despite their performance, THz systems are still limited by:

- the complexity of data interpretation;
- sensitivity to experimental conditions;
- the need for expertise in measurement analysis;
- difficulties in transferring the technology to large-scale industrial use.

The rational integration of AI represents a promising approach to overcoming these challenges, provided that the models remain consistent with the fundamental laws of electromagnetism.

Research program

Following the establishment of the state of the art through an extensive literature review, the PhD student will address the two research areas below.

Research area 1 – Intelligent pre-diagnosis and anomaly detection

The objective is to develop AI tools capable of directly exploiting certain fundamental physical constraints (causality, Kramers-Kronig relations, energy conservation, etc.) in order to:

- automatically detect inconsistent measurements;
- identify instrumental drifts;
- assist in the diagnosis of experimental errors;
- improve data quality prior to further processing.

This approach will make it possible to develop intelligent quality-control systems directly integrated into THz sensors.

Research area 2 – Advanced modeling and discovery of physical models

The second research area will focus on the development of hybrid models combining:

- Physics-Informed Neural Networks (PINNs) [11-13];

- symbolic regression [14-17];
- Kolmogorov-Arnold Networks (KANs) [18].
- explainable AI methods;
- inverse models.

These tools will be used to characterize complex materials such as:

- multilayer structures;
- scattering materials;
- metamaterials;
- materials evolving over time.

The objective is both to accelerate the extraction of physical parameters and to contribute to improving existing electromagnetic models.

Expected outcomes

This PhD thesis lies at the interface between artificial intelligence, signal processing, and wave physics. The expected results will contribute to the development of reliable and explainable smart sensors intended for a wide range of industrial sectors. Beyond the case study dedicated to the energy diagnosis of buildings, the methodologies developed could be transferred to various applications in the fields of industry, healthcare, energy, the environment, and non-destructive testing.

Candidate profile

The candidate, holding a Master's degree or an engineering degree, should have a strong background in one of the following fields:

- signal processing;
- artificial intelligence and machine learning;
- wave physics;
- electromagnetics;
- instrumentation or physical measurements;
- applied mathematics.

Skills in scientific programming (Python, Matlab, or equivalent) will be appreciated.

PhD framework and work organization

The project builds on the complementary and recognized expertise of LISTIC in the field of AI and CROMA in the field of THz waves and their applications. The candidate will benefit from an ecosystem of academic and industrial partners enabling the validation of the developments on real-world use cases and will have access to the PLATERA functional characterization platform.

The PhD will be carried out within the framework of a CIFRE agreement between PARSEWAVES, a Normandy-based deep-tech startup developing a portable sub-THz radar for the non-destructive characterization of building walls, and Université Savoie Mont Blanc (CROMA and LISTIC laboratories).

Supervision: the PhD will be supervised by Dr. Maxime Bernier (CROMA) and co-supervised by Dr. Argheesh Bhanot (LISTIC), with the participation of Pr. Alexandre Benoit (LISTIC). M. Corentin Plaine, co-founder and Chief Technology Officer of PARSEWAVES, will provide supervision on the company side.

Work location: the PhD student will be employed by PARSEWAVES and based at the company's premises in Hérouville-Saint-Clair (Caen, Normandy), within the R&D team, with a dedicated workstation for computational activities.

Monitoring: a monthly meeting via videoconference with the CROMA and LISTIC supervisors, together with regular meetings with the industrial supervisor.

Travel: one visit every six months to Le Bourget-du-Lac, and more frequently according to the needs of the project, with travel expenses covered by PARSEWAVES, particularly for measurement campaigns on the PLATERA platform.

Salary: Salary corresponding to the minimum level set by the ANRT for CIFRE agreements.

Start date: **As soon as possible.** Where possible, the selected candidate may be recruited on a fixed-term contract by PARSEWAVES upon joining the company, pending the official start of the PhD following completion of the application process by the ANRT.

Application File

CV + cover letter + transcripts (M1 and M2, or engineering school) + optionally, thesis/final project + references (internship supervisor and head of the Master's program or engineering school).

Send to maxime.bernier@univ-smb.fr

Contacts

Question about physics or administration: maxime.bernier@univ-smb.fr,

Question about AI: argheesh.bhanot@univ-smb.fr

- [1] Y. H. Tao, A. J. Fitzgerald, and V. P. Wallace, "Non-contact, non-destructive testing in various industrial sectors with terahertz technology," *Sensors*, vol. 20, no. 3, Art. no. 712, 2020, [doi: 10.3390/s20030712](https://doi.org/10.3390/s20030712).
- [2] S. Zhong, "Progress in terahertz nondestructive testing: A review," *Frontiers of Mechanical Engineering*, vol. 14, no. 3, pp. 273–281, 2019, [doi: 10.1007/s11465-018-0495-9](https://doi.org/10.1007/s11465-018-0495-9).
- [3] J. W. Jonuscheit *et al.*, "Terahertz quality inspection for automotive and aviation industries," *Journal of Infrared, Millimeter, and Terahertz Waves*, vol. 41, pp. 470–489, 2020, [doi: 10.1007/s10762-019-00639-4](https://doi.org/10.1007/s10762-019-00639-4).
- [4] L. Afsah-Hejri, P. Hajeb, P. Ara, and R. J. Ehsani, "A comprehensive review on food applications of terahertz spectroscopy and imaging," *Comprehensive Reviews in Food Science and Food Safety*, vol. 18, no. 5, pp. 1563–1621, 2019, [doi: 10.1111/1541-4337.12490](https://doi.org/10.1111/1541-4337.12490).
- [5] A. G. Davies, A. D. Burnett, W. Fan, E. H. Linfield, and J. E. Cunningham, "Terahertz spectroscopy of explosives and drugs," *Materials Today*, vol. 11, no. 3, pp. 18–26, 2008, [doi: 10.1016/S1369-7021\(08\)70016-6](https://doi.org/10.1016/S1369-7021(08)70016-6).
- [6] P. Sen *et al.*, "Multi-kilometre and multi-gigabit-per-second sub-terahertz communications for wireless backhaul applications," *Nature Electronics*, vol. 6, pp. 164–175, 2023, [doi: 10.1038/s41928-022-00897-6](https://doi.org/10.1038/s41928-022-00897-6).
- [7] L. Afsah-Hejri, E. Akbari, A. Toudeshki, T. Homayouni, A. Alizadeh, and R. Ehsani, "Terahertz spectroscopy and imaging: A review on agricultural applications," *Computers and Electronics in Agriculture*, vol. 177, Art. no. 105628, 2020, [doi: 10.1016/j.compag.2020.105628](https://doi.org/10.1016/j.compag.2020.105628).
- [8] Y.-C. Shen, "Terahertz pulsed spectroscopy and imaging for pharmaceutical applications: A review," *International Journal of Pharmaceutics*, vol. 417, nos. 1–2, pp. 48–60, 2011, [doi: 10.1016/j.ijpharm.2011.01.012](https://doi.org/10.1016/j.ijpharm.2011.01.012).
- [9] X. Yang, X. Zhao, K. Yang, Y. Liu, Y. Liu, W. Fu, and Y. Luo, "Biomedical applications of terahertz spectroscopy and imaging," *Trends in Biotechnology*, vol. 34, no. 10, pp. 810–824, 2016, [doi: 10.1016/j.tibtech.2016.04.008](https://doi.org/10.1016/j.tibtech.2016.04.008).
- [10] F. Hindle, A. Cuisset, R. Bocquet, G. Mouret, "Continuous-wave terahertz by photomixing: applications to gas phase pollutant detection and quantification," *Comptes Rendus Physique*, vol. 9, no. 2, pp. 262–275, 2007, [doi: 10.1016/j.crhy.2007.07.009](https://doi.org/10.1016/j.crhy.2007.07.009).
- [11] M. Raissi *et al.*, "Physics-Informed Neural Networks: A Deep Learning Framework for Solving Forward and Inverse Problems Involving Nonlinear Partial Differential Equations," *Journal of Computational Physics*, vol. 378, pp. 686–707, 2019, <https://doi.org/10.1016/j.jcp.2018.10.045>.
- [12] J. Berg and K. Nyström, "A Unified Deep Artificial Neural Network Approach to Partial Differential Equations in Complex Geometries," *Neurocomputing*, vol. 317, pp. 28–41, 2018, <https://doi.org/10.1016/j.neucom.2018.06.056>.
- [13] F. Udrescu *et al.*, "AI Feynman: A Physics-Inspired Method for Symbolic Regression," *Science Advances*, vol. 6, no. 16, Art. no. eaay2631, 2020, [doi: 10.1126/sciadv.aay2631](https://doi.org/10.1126/sciadv.aay2631).
- [14] K. Brenden Petersen *et al.*, "Deep symbolic regression: Recovering mathematical expressions from data via risk-seeking policy gradients," *ICLR*, 2021, <https://arxiv.org/abs/1912.04871>.
- [15] W. Tenachi *et al.*, "Deep symbolic regression for physics guided by units constraints: toward the automated discovery of physical laws," *The Astrophysical Journal*, vol. 959, no. 2, Art. no. 99, 2023, [doi: 10.3847/1538-4357/ad014c](https://doi.org/10.3847/1538-4357/ad014c).
- [16] A. Daryakenari *et al.*, "AI-Aristotle: A physics-informed framework for systems biology gray-box identification," *PLoS Computational Biology*, vol. 20, no. 3, Art. no. e1011916, 2024, <https://doi.org/10.1371/journal.pcbi.1011916>.
- [17] B. Bouvier, A. Bhanot, Y. Yan, and A. Benoit, "La régression symbolique pour la modélisation des volcans," *Rencontre Scientifique Volcanologique 2025*, June 2025, Le Bourget-du-Lac, France, [HAL: hal-05154988](https://hal.archives-ouvertes.fr/hal-05154988).
- [18] Z. Liu *et al.*, "KAN 2.0: Kolmogorov-Arnold Networks Meet Science," *arXiv preprint*, 2024, <https://arxiv.org/abs/2408.10205>.