PROGRAMME GRADUÉ ISAI

PSL UNIVERSITÉ PARIS

Titre : **Physics-Informed Artificial Intelligence for Control by Thermography**

Proposé pour un étudiant du Master :
Energy - **X** SGM - BME - **X** MNE - **X** MI/MTI
(choix multiple possible)

Laboratoire(s) d'accueil : **Centre for Mathematical Morphology – MINES Paris PSL**

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Durée du stage (en mois) : 6

The proposed subject is at the crosing of three disciplines : materials science, artificial intelligence and physics. It deals with thermographic inspection - a hot subject of importance for the industry. The thermographic inspection is a defect control method, combining considerable industrial advantages. In fact, the thermography makes it possible to detect underlying defects (eg under a coating layer), being of size below the optical resolution, requiring no chemical product and without contact with the inspected part.

The principle of thermography consists of depositing a quantity of heat on the surface of the controlled part. This heat will diffuse inside the material. In the presence of defects, the diffusion of heat is disturbed by internal heterogeneities whose position can be revealed by observing the surface temperature field [1] and detected [2]. Several very different types of materials can thus be controlled using different heating means and methods (infrared, microwaves, etc.). A drawback of this technique is the fact that it is disturbed by the surface condition (corrosion, scratches, impacts) influencing the temperature field. Today the classic technique for removing surface condition is the flying-spot thermography mode where the surface condition is removed by double inspection from left to right then right to left. Other alternative techniques to flying-spot thermography are under development, for example on the basis of frequency analysis using cyclic heating. This technique, in addition to detecting defects, also allows their characterization. The characterization of the defects requires the solution of an inverse problem – ill conditioned because of the noise present in the signal. A modern solution to this is to use neural network techniques. The now-classic approach to using neural networks consists of data simulation and then training of a predictive neural network model. Heat diffusion is simulated in the presence of artificial defects placed in a digital volume [2] and the surface temperature field is learnt to predict by a model. A large amount of data must be simulated in order to obtain a comprehensive model. Fast Fourier-based numerical computations |3] can be used to obtain artifical images representing heat diffusion in representative volume elements and train deep learning pipelines. An innovative solution consists of the use of physics-informed networks integrating the physical laws directly into the model [4, 5].

In this internship we will develop a neural network allowing to detect and characterize underlying cavities under a ceramic type coating of metallic parts. In successive steps, we will: 1) Develop a model for detecting defects in a digital volume using a single heating pulse without the presence of noise, then secondly, in the presence of noise induced by the surface condition. 2) Later, in a second step we will develop a model allowing to not only detect but also characterize defects using cyclic heating. We will estimate the size and depth of cavity-type defects.

References :

[1] Abdoulahad Thiam. Contribution à l'étude et à l'optimisation du procédé de thermographie active appliquée à la détection de défauts surfaciques. PhD thesis, Université Bourgogne Franche-Comté, 2017.

[2] Robin Alais, Problèmes de segmentation d'images et contribution à la morphologie mathématique, PhD thesis, MINES Paris PSL, January 2021

[3] F. Willot, B. Abdallah, YP Pellegrini. Fourier-based schemes with modified Green operator for computing the electrical response of heterogeneous media with accurate local fields. Int. J. Num. Meth. Engng 98, 518-533 (2014).

[4] Karniadakis, G.E., Kevrekidis, I.G., Lu, L. et al. Physics-informed machine learning. Nat Rev Phys 3, 422–440 (2021). https://doi.org/10.1038/s42254-021-00314-5

[5] N. Thuerey, P. Holl, M. Mueller, P. Schnell, F. Trost, K. Um, Physics-based Deep Learning, Book, https://arxiv.org/pdf/2109.05237.pdf

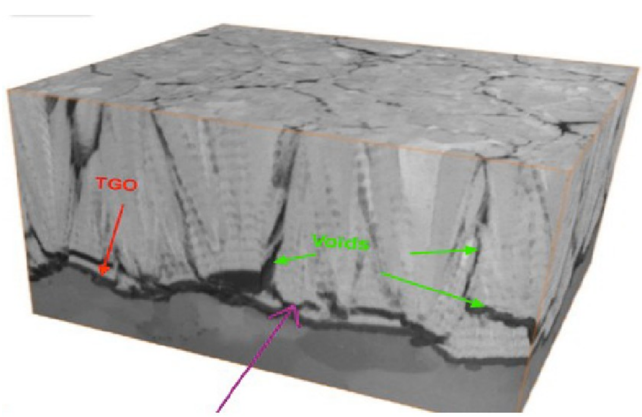

Figure 1: FIB-SEM reconstruction of the coating material showing the porosity (voids and cracks).

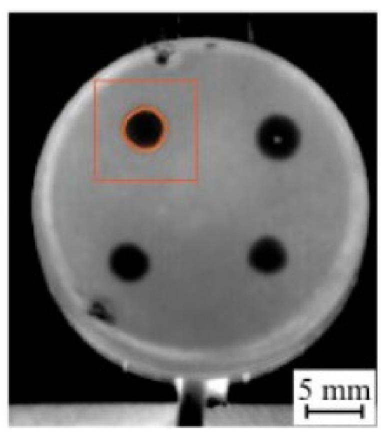

Figure 2: Example of thermogram showing artificially created defects.