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Artificial Intelligence Tools Applied to the Machine Fault Diagnosis of the Rotor-Bearing System

By

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This thesis explores the topics relevant to the application of *Artificial Intelligence* (AI) technologies to the *machine fault diagnosis* of the *rotor-bearing system*. The development of this work is part of an increasingly stringent regulatory framework towards industrial-use processes and machinery, for which it is necessary to ensure the responsible consumption of resources and high efficiency of maintenance processes. In this regard, the scientific literature developed over the past decades highlights the benefits that *predictive maintenance* techniques bring in terms of cost reduction and increased productivity and efficiency of industrial rotating systems. In particular, there is growing attention towards AI methodologies for the diagnosis and the identification of failures and malfunctions.

The dissertation examines state-of-the-art AI methodologies, their applications to machinery diagnosis, and the resulting implications. In particular, cases related to the identification of localized damages in *rolling element bearings* through vibration signal analysis are investigated. The examination is carried out by means of the experimental activity specifically set up on a test rig for medium-sized industrial bearings, available at the Mechanical Engineering laboratories of the Polytechnic University of Turin. Also, benchmark datasets known in the literature are mentioned.

The topics related to the extraction of diagnostic features from time-frequency images of vibration signals are presented in the field of *machine learning* (ML) methodologies. Among *deep learning* (DL) techniques, the diagnostic capabilities offered by *Convolutional Neural Networks* (CNNs) aimed at image and sound recognition are examined. The techniques geared to mitigating the amount of training data required to implement AI strategies are particularly investigated and implemented. It is claimed that the ability to recognize features in spectrograms could be transferred from AI-based sound recognition models toward machine diagnosis purposes since the two tasks share the need to recognize peculiarities of time-frequency images. The use of knowledge transfer techniques (*transfer learning*) acting from neural architectures pre-trained for sound recognition shows

to be effective in terms of accuracy and lowering the computational cost for the training.

The dissertation further investigates the capabilities offered by the subset of *generative AIs*, that matured and overwhelmingly flourished between 2022 and 2023 despite their origin can be traced back over the past decade. Namely, *Generative Adversarial Networks* (GANs) are applied in this work for generating training data that can compensate for the lack of actual experimental data associated with damaged machinery. The approach using GANs with *cycle-consistent* loss function (*cycleGAN*) is shown to be effective for generating training samples on the basis of simulated vibration signals. The claim proves to be valid not only for operating conditions for which the generative model was explicitly trained but also for some operating conditions that were never used in training. The generative model was implemented in the Matlab® environment and trained using the GPUs hardware available on the High-Performance Computing (HPC) cloud of Amazon® Web Services (AWS). The results produced in the case under analysis show that the data generated through GANs are able to replace real training samples for the fault diagnosis of industrial rolling bearings. It is found that *Intelligent Fault Diagnosis* (IFD) models can be trained by employing exclusively synthetic training data concerning damaged rotating machinery.

In general, results highlight that AI methodologies are concretely usable for the diagnosis of rotating machinery and the implementation of predictive maintenance strategies. Transfer learning and the CNNs pre-trained for sound recognition hereby proposed result effective for training IFD models in the presence of a small amount of training data. Also, the proposed generative model based on the cycleGAN framework results effective in generating synthetic data that compensate for the absence of real data related to damaged rotating machinery.