Intelligent computing techniques for vibration pattern analysis

Thesis submitted in partial fulfillment for the Award of Degree

Doctor of Philosophy

by

Aneesh G Nath

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI - 221005

18071018 *2021*

Chapter 7

Conclusion and Future Scope

The research works presented in this thesis mainly focused on developing a vibration-based rotor fault diagnosis system by integrating signal processing and artificial intelligence methods. The work primarily addressed SRF diagnosis and incorporated symptomatic fault component analysis, various data representations, and advanced DL strategies. The research began by collecting novel SRF raw vibration data of various working conditions of practical industrial environments. It studied the characteristics of SRF vibration, which led to the extraction and utilization of DFC in various phases of SRF diagnosis framework. The principal objective of the research was to identify and utilize the DFC of vibration patterns across multiple input data representations and classification models. This thesis has presented a novel framework that analyzed SRF data-related issues, investigated different input data representation methods such as images, sequences, and features. Then it effectively applied advanced learning strategies such as early classification, classifier fusion, and attention models.

7.1 Conclusion

The research work presented in this thesis draws the following concluding remarks.

The sensor-based integrated technology is used in modern industry for the health management of rotating machinery as it is the heart of a wide range of applications. SRF is a critical and direct fault that creates a catastrophic impact on the equipment's structural attributes and performance as well as it results in secondary faults.

The multi-sensor-based technology allows collecting a significant amount of vibration data for the health state management of rotating machinery. Therefore, in recent years, the intelligent data-driven methods have been succeeded in examining the health states of rotating machinery rather than the conventional model-based or signal-processing-based methods.

In a real working environment, rotating machinery works under different operating conditions, and thus, the classifier must provide acceptable results under such situations. Hence a novel dataset for SRF has been created by simulating the real plant environment to evaluate the framework's performance in industrial conditions, which is verified and compared with a public dataset with a wide range of speed and load conditions.

Identifying and addressing the root cause of rotating machinery faults using vibration analysis and promoting fault-characteristics-based decision-making is critical in successful rotating machinery fault diagnosis. Hence, this thesis presents a single-window reference for RFD, providing proper fault categorization, the theoretical background of rotor faults with fault characteristics analysis, a general AI-based RFD framework, and the practical fault simulation in testbeds.

SRF vibration data-related issues are addressed by TS data augmentation and data subsampling. The proposed data subsampling method, which incorporated SRF specific DFC and time-domain features, facilitated the model to perform well irrespective of the industrial data acquisition issues. The soft-DTW-based augmentation enriched the subsampled input training dataset and eliminated the class imbalance issue. The fault information content-based weighing scheme used in augmentation provided more heterogeneity and discriminative features to the synthesized samples. The proposed early classification model made the framework detect various faults based on a partial observed sequence in a real-time environment.

Multi-sensor SRF data representation using RP and FRP upholds the system dynamics and TS property and enhances the classification accuracy. The framework proposed in view of this showed efficient in generating FRPs utilizing multi-sensor data with DFC-based ranking, reducing the overall complexity. The proposed FI fusion of the CNN-based decision scores along with the LSTM based decision scores improved the results across the board to a great extent. The solution is feasible as it provides decent performance even with single sensor data. The experimental results demonstrated the efficacy of the proposed framework in satisfying objectives like TS characterization and system dynamics consideration of the input, DFC usage, and classifier fusion.

There are specific compactibility issues in applying long raw vibration sequences from multiple sensors to attention-based models. The proposed embedding representation bridge this incompatibility and endorses discriminative capability to the models. The proposed multi-sensor fusion considering attention weights and fault pattern-based ranking succeeded in ensuring the relative importance of the feature vectors of the fused sensors. The basic transformer and two recurrent transformer models utilized the long-term dependency as well as the local dependency from the embedded tokens in the classification phase.

Thus the research work performed in this thesis efficiently dealt with data collection issues, domain-specific data representation, SRF symptom parameter usage, sensor fusion, sequential learning and advanced DL strategies with vibration data in view of SRF fault diagnosis. Thereby all the proposed models produced significantly better results compared to the state-of-the-art SRF diagnosis solutions.

7.2 Future Scope

It may be worth pointing out that there is significant scope for enhancement in the proposed fault diagnosis methods. Based on the research work presented in this thesis, the following are the future direction to explore more.

- GAN-based data generation is one of the methods that can be adopted to address the data scarcity issues.
- Dealing with actual industrial data poses various challenges in SRF diagnosis; hence it is recommended to collect more industrial datasets and develop solutions based on real plant issues. The misclassification of SRF can be addressed by capturing the data using heterogeneous sensors for more specific information about the faults.
- This work can be extended on joint FRPs and improved TS imaging techniques. Similarly, more weighted sensor fusion strategies can be introduced to deal with multi-sensor data.
- More opportunities are there in classifier fusion and transfer learning kind of new learning strategies. Classifiers can be fused at different levels such as data-level, feature-level, decision level, etc. Similarly, we can train the models with artificial faults and the transferring of the trained model for the categorization of natural faults in a real-world scenario.
- Most RFD research has focused on studying single faults, ignoring the compound faults, which do not reflect the real-world scenario. The research considering the compound faults as a multi-labeling problem is more realistic and challenging from the fault diagnosis perspective.
- It would be advantageous to explore more SRF solutions by addressing the problems using techniques like multiobjective optimization.