Final report for project "Hybrid Methods for Fault Diagnosis and Prognostics" CENIIT 2020 – 2025

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A summary of the most important scientific results

The CENIIT funding has helped me to develop the fault diagnosis research activities at Vehicular Systems. The project have contributed to several research results in the area of fault diagnosis and applied scientific machine learning. One main contribution is bridging model-based fault diagnosis theory and data-driven fault diagnosis. We have developed a hybrid fault diagnosis framework for detection of abnormal system behavior and reasoning about its cause combining physically-based models and available training data. Our research have shown how to use ML to reason about unknown faults and developing data-driven models for fault diagnosis that can generalize from limited training data. To inspire more research in this direction I have also introduced a fault diagnosis benchmark, the LiU-ICE benchmark, that has been used in two scientific competitions.

One interesting research direction that was initialized from this project was the systematic design of NODE-based residual generators using physical insights for fault detection and isolation. We have developed techniques for selecting model structures for fault isolation and parameter initialization for a type of neural networks called Neural Ordinary Differential Equations (NODE) to speed up the training process. This research has bridged simulation methods and theory to training of neural networks.

Degrees and promotions the project has contributed to

This project allowed me to obtain the degree of Docent in Electrical Engineering in April 2020. It also contributed to me becoming ELLIIT Recruited Faculty as an Associate Professor in Diagnostics and Prognostics at the Department of Electrical Engineering in May 2022.

This project has also been important for Arman Mohammadi to obtain his PhD degree in December 2025.

A summary of masters thesis works that have been performed within the project

Multiple thesis projects have been carried out in the project covering different aspects of fault diagnosis, where some also contributed to scientific publications.

1. M. Sadeghi Naeini, Fault Detection of Internal Combustion Engine: Exploring Dynamic Relations with SINDy and AR Models for Engine Sensor Fault Detection, 2024
2. S. Saber, Battery Degradation and Health Monitoring in Lithium-Ion Batteries: An Evaluation of Parameterization and Sensor Fusion Strategies, 2024.
3. Emely Björkkvist och Felix Eriksson, Data-Driven Diagnosis For Fuel Injectors Of Diesel Engines In Heavy-Duty Trucks, 2024.
4. Viktor Erlandsson och Max Idermark, Vibration Health Monitoring Using a Flight-State Aware Autoencoder on a Helicopter Main Rotor, 2024.
5. Isak Ederlöv och Viktor Mineur, Diagnosis of a Precision-Planting System, 2024.
6. Ninos Baravdish, Information Fusion of Data-Driven Engine Fault Classification from Multiple Algorithms, 2021.
7. Johan Lindström, Model-Based Fault Diagnosis of an Electrical Low-Voltage Grid, 2021.
8. Kevin Lindström, Fault Clustering With Unsupervised Learning Using a Modified Gaussian Mixture Model and Expectation Maximization, 2021.
9. Joakim Säfdal, Data-Driven Engine Fault Classification and Severity Estimation Using Interpolated Fault Modes from Limited Training Data, 2021.
10. Andreas Lundgren, Data-Driven Engine Fault Classification and Severity Estimation Using Residuals and Data, 2020.

A summary of persons funded by the project

Except myself, this project has partially funded research activities conducted of the following persons:

- Andreas Lundgren was funded during summer 2020.
- Arman Mohammadi has been part of this project since January 2021.
- Niklas Allansson was funded during summer 2023.
- David Axelsson was funded during summer 2024.

A summary of which industrial connections the project has had and how scientific results have been transferred to the industrial partners

This project has been conducted in close collaboration with multiple industrial partners. The main collaborating partners have been Scania and Volvo Cars. They have provided different industrial case studies that have inspired new research and evaluated the developed methods in realistic applications.

A list of publications

PhD thesis:

1. A. Mohammadi. Machine Learning for Fault Diagnosis of Industrial Systems. Linköping Studies in Science and Technology. Dissertations no 2497, ISSN 0345-7524. 2025.

Peer reviewed journal papers:

1. D. Jung, T. Westny. Uncertainty-aware fault diagnosis of unknown faults using ensemble-based NODE residuals, *Mechanical Systems and Signal Processing*. 2026.

2. D. Jung, E. Frisk, M. Krysander, A. Sztyber-Betley, F. Corrini, A. Arici, N. Anselmi, M. Mazzoleni, J. Xu, S. Mo, Z. Xu, C. Yang, Z. Du, H. Safaeipour, M. Forouzanfar, V. Mirahi, A. Pinnarelli, V. Puig, Q. Deng, Y. Liu, J. Liu, H. Ke, W. Zhu, S. Merkelbach, M. Ahang, H. Najjaran. A fault diagnosis benchmark of technical systems with incomplete data – six solutions, *Control Engineering Practice*, 164. November 2025.

3. V. Renganathan, D. Jung, E. Yurtsever, Q. Ahmed. Learning robust residuals for attack diagnosis of advanced driver assist systems, *Control Engineering Practice*, 162. September 2025.

4. A. Mohammadi, M. Krysander, D. Jung. Consistency-based diagnosis using data-driven residuals and limited training data, *Control Engineering Practice*, 159. June 2025.

5. V. Renganathan, Q. Ahmed and D. Jung. Enhancing the Security of Automotive Systems using Attackability Index. *IEEE Transactions on Intelligent Vehicles*. November 2023.

6. A. Lundgren and D. Jung. Data-Driven Fault Diagnosis Analysis and Open-Set Classification of Time-Series Data. *Control Engineering Practice*. vol. 121, 105006, April 2022.

7. S. Voronov, D. Jung, and E. Frisk. A Forest-based Algorithm for Selecting Informative Variables Using Variable Depth Distribution. *Engineering Applications of Artificial Intelligence*. 97, 104073. 2021.

8. D. Jung. Distributed Feature Selection for Multi-class Classification Using ADMM. *IEEE Control System Letters*. 5(3), 821-826. 2020. (Presented at IEEE Conference on Decision and Control, 2020)

9. D. Jung. Data-driven Open Set Fault Classification of Residual Data using Bayesian Filtering. *IEEE Transactions on Control System Technology*. 28(5), 2045-2052. 2020.

Conference papers:

1. I. Pill, D. Jung, E. Kurudzija, A. Sztyber-Betley, M. Syfert, K. Dresia, G. Waxenegger-Wilfing, J. de Kleer, The DX Competition 2025 and Its Benchmarks, *36th International Conference on Principles of Diagnosis and Resilient Systems (DX 2025)*, Nashville, USA. 2025.

2. D. Jung, M. Krysander, Assumption-based Design of Hybrid Diagnosis Systems: Analyzing Model-based and Data-driven Principles, *Annual Conference of the PHM Society*. Nashville, TN, USA. 2024.

3. D Jung, D Axelsson, A Study on Redundancy and Intrinsic Dimension for Data-Driven Fault Diagnosis, *35th International Conference on Principles of Diagnosis and Resilient Systems (DX 2024)*, Vienna, Austria. 2024.
(Best Paper Award)

4. N. Allansson, A. Mohammadi, D. Jung, M. Krysander, Fuel injection fault diagnosis using structural analysis and data-driven residuals, *12th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes*, Ferrara, Italy, 2024.

5. T. Westny, A. Mohammadi, D. Jung, E. Frisk, Stability-Informed Initialization of Neural Ordinary Differential Equations, *International Conference in Machine Learning*, 2024.

6. D. Jung, M. Krysander, A. Mohammadi, Fault diagnosis using data-driven residuals for anomaly classification with incomplete training data, *22nd IFAC World Congress*, Yokohama, Japan, 2023.

7. A. Mohammadi, T. Westny, D. Jung, and M. Krysander, Analysis of numerical integration in RNN-based residuals for fault diagnosis of dynamic systems, *22nd IFAC World Congress*, Yokohama, Japan, 2023.

8. D. Jung and J. Säfdal, A flexi-pipe model for residual-based engine fault diagnosis to handle incomplete data and class overlapping, *10th IFAC Symposium on Advances in Automotive Control*, Columbus, OH, USA, 2022.

9. D. Jung, B. Kleman, H. Lindgren, and H. Warnquist, Fault Diagnosis of Exhaust Gas Treatment System Combining Physical Insights and Neural Networks, *10th IFAC Symposium on Advances in Automotive Control*, Columbus, OH, USA, 2022.

10. D. Jung, Automated Design of Grey-Box Recurrent Neural Networks For Fault Diagnosis using Structural Models and Causal Information, *Learning for Dynamics and Control*, Stanford, CA, USA, 2022.

11. E. Frisk, F. Jarmolowitz, D. Jung, and M. Krysander, Fault Diagnosis Using Data, Models, or Both–An Electrical Motor Use-Case, *11th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes*, Cyprus, 2022.

12. K. Lindström, M. Johansson, and D. Jung, A Data-Driven Clustering Algorithm for Residual Data Using Fault Signatures and Expectation Maximization, *11th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes*, Cyprus, 2022.

13. A. Mohammadi, M. Krysander, and D. Jung, Analysis of grey-box neural network-based residuals for consistency-based fault diagnosis, *11th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes*, Cyprus, 2022.

14. D. Jung, Structural Methods for Distributed Fault Diagnosis of Large-Scale Systems, *IEEE Conference on Decision and Control*, Korea, 2020.

15. D. Jung, Isolation and Localization of Unknown Faults Using Neural Network-Based Residuals. *Annual Conference of the PHM Society.* Scottsdale, AZ, USA. 2019.