Special Issue on Advanced Diagnostics and Prognostics for Automotive Systems

Editorial Letter from the Guest Editors and Review Managers
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With elevated system complexity in electrified powertrains, connectivity, and automated driving; new Diagnostics and Prognostics (DnP) analytics and technologies are emerging to support accurate and reliable estimation and predictions of state of health for complex vehicular systems, during a complete life cycle from manufacturing to final product usage. The increased capability of the vehicle and its manufacturing processes to exchange data with passengers, surrounding infrastructure, and other vehicles has been both an enabler and provide motivation for developing advanced vehicle health management (VHM) features. On the other hand, recent advances in systems and analytics tools such as machine learning and cloud-based computation is leveraging the classic model based DnP algorithms to address the complexities, and performance requirements of future VHM systems.

This special issue on Advanced Diagnostics and Prognostics for Automotive Systems provides an opportunity to discuss recent advances in different topics related to modern automotive systems. The topics include model-based monitoring algorithm for diesel vehicle aftertreatment system, air-path health management strategy for estimation of the mass flows and mitigation of the air-path faults, early detection of anomalies in fuel system evaporative and purge systems leveraging vehicles connectivity, review of intelligent maintenance of EVs at both component level and system level to identify existing gaps in EVs DnP, detection and isolation of ground connection faults in electronic control units, root cause detection of defects in arc stud welding that is used to join automotive structures, machine learning based anomaly detection framework demonstrated on the hydraulic system of electric off-road vehicles, and signal abstraction to assist fast root-cause detection of large scale control systems.

In the first paper, Kaushal et al., present a diagnostics-oriented aging model for combined Selective Catalytic Reduction (SCR) and Ammonia Slip Catalyst (ASC) system, along with a model-based onboard diagnostic (OBD) method applied to both test-cell data and on-road data from commercial trucks. The key challenge with model development was unavailability of NOx and NH3 measurements between SCR and ASC. Since it would have been very difficult to calibrate both SCR and ASC dynamics without any measurements between SCR and ASC, therefore ASC was modeled using static look-up tables to determine ASC's NH3 conversion efficiency and its selectivity to NOx and N2O as a function of temperature and flow rate. The traditional three-state single-cell ordinary differential equation (ODE) model was used for SCR. Hot Federal Test Procedure (hFTP) was used to calibrate the model. Cold FTP (cFTP) and Ramped Mode Cycle (RMC) were used for validation. Results show that the SCR-ASC model can capture the aging signatures in tailpipe NOx, NH3, and N2O reasonably well for cFTP, hFTP, and RMC cycles in the test-cell data. After slight re-calibration and combining with a simple model for commercial NOx sensor's cross-sensitivity to NH3, the model works reasonably well for on-road data from commercial trucks. A model-based on-board diagnostic (OBD) method has been

presented with enable conditions designed to detect operating conditions suitable for detecting aging signatures, while minimizing false positives and false negatives. The OBD method is applied to both test-cell and real-world truck data with commercial NOx sensors. Reasonable results demonstrate that the diagnostics-oriented model presented in this work is suitable for developing model-based OBD that can work for SCR-ASC system on commercial trucks.

Next, Poloni et al., present an air-path health management strategy with the ability to estimate the mass flows and mitigate the air-path faults in the exhaust system of a heavy-duty diesel combustion engine, equipped with a twin-scroll turbine. Based on the engine component models applied in the quasi-steady-state mass-balancing approach, two main engine mass-flow quantities are estimated: the Air mass flow (AMF) and the Exhaust gas recirculation (EGR) mass flow. The health management system is monitoring for three kinds of air-path faults that can occur through the combustion engine operation, related either to the after-treatment system, EGR valve, or to the turbine balance valve hardware. For each fault, a fault-mitigation strategy based on in-observer-reconfigurable mass-balance equations with excluded faulty component model and utilized exhaust pressure sensor is proposed. The applied observer is using the iterated Kalman filter (IKF) as the core fault mitigating solver for the quasi-steady-state mass balancing problem. It is further demonstrated how the individual faults are robustly isolated using the Sequential Probability Ratio Test (SPRT). The strategy and results are validated using the test cycle driving data.

Omrani et al. use Mode06 (On-Board diagnostics reported tests results) connected vehicle data along with contextual data to early detect EVAP and purge monitors' anomalies for early detection that allows fixing the issue through software (SW) and/or hardware (HW) upgrades before it turns into a failure (preventive maintenance), yielding then system quality improvement. The paper discusses statistics-based early anomaly detection models, based on vehicle data and fleet data. The proposed solution is a generic tool that doesn't make assumptions on data distribution and can be adapted to other systems by tweaking mainly the data cleaning process. It also incorporates specific system definitions of abnormal behavior, which makes it more accurate compared to conventional anomaly detection tools, which are mainly affected by the imbalanced data and the EVAP and purge definition of an anomaly. When deployed with field data, the algorithm showed higher performance, compared to popular anomaly detection techniques, and proved that failures can be prevented through detection of the anomalies several weeks/miles before the actual fail.

In the paper by Hsu et. al., the authors review EV-related issues beginning with the component level, through the system level, based on intelligent maintenance aspects. The paper also explores the existing gaps in practical applications and highlight the potential opportunities related to the current issues in EVs for the EV industry moving forward. More specifically, the paper briefly starts with an overview of the fast-growing EV market, showing the urgent demand for Prognostics and Health Management (PHM) applications in the EV industry. At the component level, the issues of the major components such as the motor, battery, and charging system in EVs are elaborated, and the relevant PHM research of these components is surveyed to show the development in the era of EV expansion. Moreover, the impact of an increasing number of EVs at the system level such as power distribution systems and power grid are explored to uncover possible research in the future. Four aspects of vision in the overall charging network – battery innovation, charging optimization, infrastructure evolution, and sustainability – that cover the demands of research in new battery materials, innovative charging techniques, new architectures of the charging network, and reliable waste treatment mechanisms are outlined. A conclusion is reached in this paper by summarizing the opportunities for future EV research and development.

Modern vehicles rely on a network of electronic control units (ECUs) to provide ever-proliferating vehicle functionalities. The paper authored by Du, et. al. addresses a common and critical vehicle ECU issue, namely, ground connection faults, which may cause temporary or permanent absence of ECU and negatively impact vehicle performance. Based on careful analysis of controller area network (CAN) communication protocol, the authors first present the model of the ground faults with ECUs. They subsequently propose the solution to detect the offset and floating ground faults by monitoring bus voltages within communication data frames and between frames, respectively, as well as additional ECU activity information. The fault location isolation method is presented next by analyzing the delay between the voltage measurement and message reading. The proposed approach is implemented on a cost-effective Arduino-based test box, and validated on a vehicle frame with three CAN buses and ten plus ECU modules with extensive experiments.

Sadra Naddaf-Sh et. al. present a paper to diagnose the possible leading causes of defects in arc stud welding, which is widely used by automotive and shipbuilding industry to join large-scale structures. The solution starts from employing independent component analysis (ICA) and dynamic time warping (DTW) on the raw time series measurements, such as voltage and current, to generate the residual dataset. After normalization, the data is fed to five different models, namely, multilayer perceptron (MLP), Fully Convolutional Network (FCN), Residual network (ResNet), and XCM, to classify six classes of defective welds, including four types of pollution on the welding surface and two types of defects made on stud quality and electrical system. The authors utilized a Bayesian method to optimize the hyper parameters of the models in order to achieve better classification performance. The proposed framework and algorithms are validated on a dataset of defective welds synthetically generated with known root causes of the defects. Finally, the paper presents how the XCM model decides on features to classify signals as well as its time attention, which provides some insight to the decision making process of the classification model.

In the paper by Aditya Jain and Piyush Tarey, the authors build upon the observation that vehicle design is getting more and more complicated, and point out the critical requirements of prognostics and predictive maintenance for smart vehicles to cover both known and new failure modes. A machine learning (ML) based anomaly detection framework is then proposed that utilizes minimally labelled or unlabeled sensor data. The framework includes subsequent stages kobalt 24v batteryof data processing, data analysis, regime Identification, modeling, model validation and deployment, and data labeling. A case study of anomaly detection in the hydraulic eufy system of electric off-road vehicle is presented to illustrate the effectiveness of the proposed framework, using the data collected from more than 40 vehicles via telemetry devices. The experimental results show that the one-class SVM based method outperforms the method based on Isolation Forest and Local Outlier Factor. The authors also provide some initial perspective in the conclusion section about the need of continuous performance monitoring in order to extend a deployed system to deal with specific operating conditions that are not defined during the design stage of the system.

The complexity of root cause identification in large scale control systems is addressed in the paper by Salehi and Shiming- where an abstraction method is presented to identify the most important signals for a root cause analysis by leveraging data collected from a connected fleet of field vehicles. A novel label propagation methodology is proposed to select the most relevant signals for the root cause analysis by detecting linear and nonlinear correlations between an observed malfunction and candidate test signals of the control system. The proposed label propagation method eliminates the requirement for a priori known correlation kernel that is needed for a regression analysis. The signal abstraction method is applied and successfully tested for

abstracting signals in the fuel control system, with high degree of interconnection between software and hardware, using data from more than 5000 connected vehicles.

We hope that this special issue of the International Journal of PHM will advance the awareness about innovations in the development of VHM technologies in automotive systems and manufacturing. Also, all the reviewers of this issue who dedicated their valuable time to provide comments that have significantly improved the quality of published papers are greatly appreciated.

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