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An Online Degradation Forecasting and Abatement Framework for Hybrid Electric Vehicles

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Abstract

The increasing electrification of vehicles raises system reliability concerns as the electrical and electronic components deteriorate faster after an event. In addition, the traditional method of scheduled maintenance is not efficient for managing a fleet of vehicles; because, the degradation processes are distinct in different vehicles. Therefore, integrating an online degradation forecasting and abatement module into a vehicle that is able to assess the vehicle status and predict the degradation process to take timely appropriate actions to reach satisfactory reliability and long-term goals, is valuable. Quantifying uncertainty is one of the main challenges of degradation forecasting; because, the degradation process of a vehicular system is distinct. This paper proposes an online degradation forecasting framework to predict the degradation processes to reallocate energy sources in the system, obtaining long-term goals while adhering to the reliability requirements. The proposed method consists a sequence of blocks: 1) representation, 2) combination, 3) propagation and 4) decision making to reliably quantify uncertainty.

Introduction

Vehicle electrification has received significant interest over the years [1, 2]. The primary driving factors of adopting electrified vehicles are fuel-saving and pollution reduction benefits. Also, electrification brings other benefits for applications that require quiet mobility and obscured thermal signature. Since electric vehicles (EVs) still have limitations mainly from energy storage and charging technologies, hybrid electric vehicles (HEVs) are considered as an alternative until a full transformation to EVs is achieved.

Evidently, electrification increases the penetration level of electrical components in a vehicle. In some HEV powertrain configurations, the primary energy source is an energy storage system (ESS) and the secondary source is an internal combustion engine (ICE) [3]. Additionally, various power electronic converters are deployed into an HEV. Electrical components deteriorate faster than mechanical components after accidents resulting in damage. Electrification and advancements in the semiconductor industry eases the deployment of computational devices and signal processing operations, which allows for the online implementation of computationally demanding activities such as forecasting.

The traditional methods of periodic maintenance do not perform well for a fleet of vehicles due to the heterogeneous nature of the degradation process. It is not necessary that two components have the same degradation behavior in the same model. In the United States, degradation patterns of electric vehicle batteries vary from one state to another [4]. While redundant maintenance increases the operation and maintenance cost (OM), not doing so in a timely manner can lead to costly failures in midst of operation in a critical mission.

The cost-saving goal in HEVs is realized by the implementation of energy management (EM) [5, 6, 7, 8, 9]. The underlying concept of EM is to solve an optimization problem in a well-defined manner to find optimal energy allocation set points among different sources. EM outputs are then passed down as input to lower control layers; therefore, time constraints must be considered in EM. To achieve real-time EM implementation, the optimization problem should consider a limited number of aspects.

With the above considerations, it is imperative to maintain the highest reliability in the system. So, degradation models alongside appropriate decision-making strategies are developed to integrate the component status information into the control. A degradation forecasting (DF) layer is developed considering a certain time horizon to 1) give timely advisory actions to avoid unpleasant events, 2) maintain required reliability indices, 3) gain long-term economic benefits compared to instant EM cost savings. Since customers may not be HEV experts, the DF outcomes should be understandable for non-experts, so they can take appropriate action.

Quantifying uncertainty in DF is a challenging task. Degradation process data are scarce, because generating them is challenging, costly, and time-consuming. In addition, degradation processes are impacted by various internal and external variables of a component. Uncertainty is classified into two types: aleatory and epistemic [10]. While aleatory uncertainty comes from the inherent variability associated with a physical system or environment; epistemic uncertainty

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