European Network for Business and Industrial Statistics

Contribution ID: **25** Type: **not specified**

A Data-Driven Health Indicator for Condition Monitoring of Electric Vehicles

The increasing availability of high-frequency telemetry data in electric vehicles (EVs) creates new opportunities for monitoring system health. Within the broader context of Prognostics and Health Management (PHM), these data streams have the potential to facilitate the transition from reactive maintenance to evidence-based condition assessment. However, in real-world industrial settings, reliable labels for faults, maintenance interventions or remaining useful life (RUL) are often incomplete, inconsistent or unavailable. This restricts the effectiveness of supervised predictive modelling and necessitates the development of statistical approaches that can operate without explicit degradation benchmarks.
This work proposes a data-driven framework for developing a Vehicle Condition Indicator (VCI): an interpretable, synthetic measure of vehicle health derived from heterogeneous, multisensory telemetry. The framework's primary methodological contribution is the definition of a statistically robust indicator that can capture deviations from normal behaviour while remaining stable under different operating conditions.
The framework integrates multivariate statistical monitoring and unsupervised learning techniques into a consistent modelling approach. In particular, baseline operating regimes are identified through dimensionality reduction and clustering to characterise nominal system behaviour. This modelling step enables normal variability due to usage conditions to be separated from structurally atypical behaviour. Any deviations from these patterns are quantified using metrics based on distance and density, and their temporal evolution is analysed to distinguish persistent shifts, which may be associated with degradation processes, from transient anomalies.
The resulting VCI is not intended to be a black-box score. It is designed to be interpretable and can be broken down into subsystems, such as the battery, power electronics or braking system. This breakdown provides diagnostic proxies that support engineering analysis, even when labelled failures are absent. Rather than directly estimating RUL, the indicator provides a continuous, comparable measure of relative condition which can be monitored over time and across vehicles operating under different duty cycles, thus supporting PHM decision processes without relying on fully supervised degradation models.
A case study based on real-world EV telemetry data illustrates the statistical properties and practical relevance of the proposed indicator. The analysis shows how the VCI captures emerging behavioural changes before explicit faults are recorded, enabling consistent health ranking across vehicles with different usage profiles. Although it was developed for EVs, the framework can easily be transferred to other complex industrial systems characterised by high-dimensional telemetry and scarce labels. By basing condition monitoring on interpretable multivariate statistics rather than purely predictive modelling, this work aims to stimulate discussion within the business and industrial statistics community on robust and scalable approaches to data-driven health assessment.

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Track Classification: Spring Meeting