

## ABSTRACT

---

The extensive use of high-end automated assets in an automotive sector is the current paradigm shift as a prerequisite of Industry 4.0. In tandem, the life cycle assessment is the prerequisite for such automated systems to optimize the return on this significant investment. Today's market places increasing emphasis on quality efficiency and environmental performance. Scientific understanding of the degradation process and its phenomena is essential for designing and achieving optimal performance. Even before designing high-performance, environmentally friendly gadgets, a product's life cycle optimization is critical. Machine downtime due to maintainability and system component replacement is quite often associated with elevated expenses. Present work is motivated towards developing a computationally efficient system health prognostics methodology directed towards enhanced performance within optimized cost and safety standards. System's health assessment under actual operating conditions and its future state prediction very often helps in developing an effective maintenance plan. Data-driven models are employed to take advantage of condition based maintenance (CBM), which provides an optimized maintenance strategy for estimating the system's remaining useful life (RUL).

The proposed work utilizes data driven models to predict the RUL of a clutch actuator motor in an electric automated manual transmission (*e*-AMT) application. In an *e*-AMT car, the electromechanical actuator works in tandem with a permanent magnet direct current (PMDC) motor to facilitate automated clutch operation, and any failure or decrease in performance of this motor potentially cause the vehicle to stall. Motor degradation is characterized by a deviation in their performance parameters from their initial values. The change in parameters in turn will cause degradation in performance of the clutch along with the motor which is a part of the clutch assembly, eventually leading to function failure of the system. Current methods for forecasting failures triggered by electronic component faults rely on defining monotonically deviating parameters and modeling their evolution over time. This dissertation establishes a prognostics approach that uses machine learning features derived for an electrical motor response to solve this issue. Exponential degradation modeling and the three variants of particle filter (PF) are applied in the development of an efficient reliability methodology for predicting automotive motor failure. Subsequently, the robust and reliable techniques for motor RUL prediction will support scheduling an optimal maintenance plan.

First, the degradation model to exhibit the state of health of the clutch was developed. The initial step has been in the selection of an appropriate prognostic parameter. Unusual patterns in the sensor data set collected from experiments indicated that current ( $I_a$ ) is one such prognostic parameter to indicate the state of the health of the clutch. A novel condition indicator (CI) and a threshold for a conditionally independent noisy signal from the motor subjected to cumulative degradation were established. A dominating feature characterizing the motor health was discerned amongst time, frequency and time-frequency domain and identified while analyzing the time-series signal composed of an agglomeration of different frequencies that produce higher octaves. Tests for monotonicity and trendability metrics affirmed a distinguishing CI. Principal component analysis (PCA) allowed the fusion of features for the selection of the best-performing CI. The proposed CI was used in an exponential degradation model to predict the RUL of the motor accurately.

The second part of the thesis involves the application of three variants of particle filter (PF) with various resampling techniques to account for heavy-tailed observations and non-Gaussian characteristic of noise to improve the accuracy of RUL estimation. The prediction of the motor's RUL is pursued by a model-based filtering method that relies on an empirical model and a stochastic filtering technique. The empirical model describes the degradation in clutch health with the progression of the fault in a motor component. The stochastic filtering technique on the other hand was used to first solve the 'motor health state' estimation problem, followed by a prediction problem in which the estimated motor health state is extrapolated forward in time to predict RUL. A comparative analysis of the results showed major enhancement in the prediction accuracy respectively and in the efficacy of RUL estimation due to traditional PF, unscented particle filter (UPF), and improved unscented particle filters (*i*-UPF) vis-a-vis the ordinarily fitted exponential degradation model.

Further, the verification and validation of the prognostic models have been performed utilizing the benchmark Li-ion battery data from the repository of NASA, Prognostics Centre of Excellence (PCoE). The resulting accuracy within the existing 10% results itself validates the superiority of the proposed scheme. This work shows the effectiveness of adaptive filtering techniques towards efficient predictive maintenance (PdM) by employing analytics, which are methods and techniques that use asset data, such as condition and loading data, or experience, to detect or predict changes in the physical condition of the equipment. By integrating PdM in current industrial practices, the use of these analytics contributes to a larger shift towards Industry 4.0.