Lubricant oil degradation is a major cause of failures in transportation machinery such as pumps, engines, and gearboxes. Proactive oil maintenance techniques such as the off-line oil sampling for laboratory analysis are not only costly but are also susceptible to various influences during the oil sampling, transportation and testing. In this study, an on-line oil condition monitoring system is presented with an integrated predictive prognostic scheme, describing the evolution in time of the identified fault indicators for purposes of estimating the remaining useful life of oil in real-time inside the gearbox. The proposed methodology facilitates on-demand gearbox maintenance rather than the conventional rigid routine inspections, which improves the ecological and economic efficiency by minimizing the vehicle’s downtime and maximizing productivity.
One of the challenges of an on-line gearbox lubricant condition monitoring for improved prognostic accuracy, is the extraction of useful information from signals containing contributions from many dynamic parameters and embedded noise, while remaining innocuous to the lubrication system. In this study, extensive theoretical analysis and experimental work has been conducted to evaluate the lubricant oil degradation as it ages under various operating regimes, including the origins, propagation mechanisms and the effects of primary contaminants, namely: oxidative degradation, water and particle contamination. A monitoring system for particle contaminants in oil has been investigated, a prototype system has been developed using a Hall effect transducer and prototype system has been successfully characterized in a simulated gearbox environment. A commercially available multi-functional sensor comprising of a tuning fork resonator, humidity sensor and temperature sensor has been adapted for oil viscosity, water content and oil temperature monitoring respectively, in a harsh gearbox environment. The experimental work is presented including a detailed description of the tests’ set-up and the measurement results. The results have been shown to validate theoretical predictions and have also been compared against established off-site laboratory techniques to validate the accuracy of the chosen oil condition monitoring methodology. The effects of concurrent multiple contaminants have also been investigated to characterize the susceptibility of the monitored parameters in the presence of more than one contaminant.

Bayesian probabilistic estimation technique called particle filtering has been applied for on-line estimation and prediction of an evolving set of parameters by modeling the hypothesis uncertainty of a dynamic system using recursive filtering algorithms. Physics-based models have been developed empirically to augment experimental data in order to quantify the relationship between the identified lubricant contaminants and the gearbox performance metrics. Mathematical concepts behind particle filtering algorithms have been presented along with the algorithms implementation. Several case studies have been conducted to simulate various industrial scenarios to validate the accuracy of the chosen oil condition monitoring methodology and the robustness of the developed novel physics models in predicting the remaining useful life using both computer simulation and physical experiments.