Special Session X

Special Session Basic Information:

专栏题目 **Session Title**	中文：复杂工况下的智能故障诊断与寿命预测 英文：Intelligent Fault Diagnosis and Lifetime Prediction under Complex Operating Conditions

专栏介绍和征稿主题
Introduction and topics

中文： 在复杂工况与多源环境下，工业系统的健康状态诊断与寿命预测面临诸多挑战。设备运行过程中常伴随强噪声干扰、工况条件交替以及多源信息耦合，使得传统的退化建模与寿命预测方法在准确性和鲁棒性方面存在不足。因此，如何在复杂环境中实现有效的特征提取、复合故障识别以及跨工况剩余寿命预测，成为当前可靠性与健康管理领域的重要研究问题。

本专题关注复杂工况下的诊断与预测建模方法，重点探讨信号处理、统计推断与智能学习等方法在理论与应用层面的最新进展。征稿主题包括但不限于：

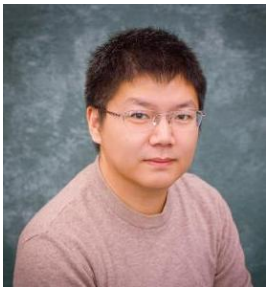
1. 信号处理与故障诊断：复杂噪声与多源环境下的信号特征提取、复合故障建模与识别方法
2. 智能学习与预测建模：数据驱动与机器学习方法在寿命预测中的应用、跨工况与时变条件下的预测建模
3. 退化建模与统计推断：复杂工况与多元环境下的退化过程建模、不确定性量化与统计推断

英文： Under complex operating conditions and multi-source environments, health condition diagnosis and lifetime/remaining useful life (RUL) prediction of industrial systems face considerable challenges. During operation, severe noise interference, time-varying operating conditions, and multi-source signal coupling often reduce the accuracy and robustness of traditional degradation modeling and lifetime prediction methods. Therefore, achieving effective feature extraction, compound fault diagnosis, and cross-condition RUL prediction has become an important research challenge in the field of reliability and health management.

This special session focuses on diagnostic and predictive modeling methods under complex operating conditions, with particular emphasis on recent advances in signal processing, statistical inference, and intelligent learning from both theoretical developments and practical applications. Topics of interest include, but are not limited to:

1. Signal Processing and Fault Diagnosis: Feature extraction under noisy and multi-source environments; compound fault modeling and diagnosis methods
2. Intelligent Learning and Predictive Modeling: Data-driven and machine learning approaches for lifetime prediction; predictive modeling under cross-condition and time-varying operating environments
3. Degradation Modeling and Statistical Inference: Degradation process modeling under complex and heterogeneous conditions; uncertainty quantification and statistical inference methods.

Special Session Chair(s):



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Organizer's Brief Biography

中文：陈飘，浙江大学伊利诺伊大学厄巴纳香槟校区联合学院副教授，博士生导师，国家级青年人才。2013 年本科毕业于上海交通大学工业工程系，2017 年博士毕业于新加坡国立大学工业系统工程与管理系。在加入浙江大学之前，曾担任荷兰 TU Delft 统计系助理教授。主要研究方向为质量与可靠性、统计学习、决策优化等。在管理、工程、统计等交叉领域的重要期刊如 Management Science, Production and Operations Management 和 IEEE Transactions on Information Theory 上发表论文 30 余篇。成果多次获国际会议最佳论文奖，包括 INFORMS QSR, SRSE, STARF 等。

英文： Piao Chen is an Associate Professor and Ph.D. supervisor at the ZJU-UIUC Institute, Zhejiang University, and a recipient of a national-level youth talent program. He received his B.S. degree in Industrial Engineering from Shanghai Jiao Tong University in 2013 and his Ph.D. degree from the Department of Industrial Systems Engineering and Management at the National University of Singapore in 2017. Before joining Zhejiang University, he served as an Assistant Professor in the Department of Statistics at TU Delft, the Netherlands. His research interests include quality and reliability, statistical learning, and decision optimization. He has published more than 30 papers in leading journals across management, engineering, and statistics, such as Management Science, Production and Operations Management, and IEEE Transactions on Information Theory. His work has received multiple Best Paper Awards at international conferences, including INFORMS QSR, SRSE, and STARF.

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Organizer's Brief Biography

中文：罗春玲，杭州师范大学教授，博士生导师。本科毕业于上海交通大学工业工程专业，博士毕业于新加坡国立大学工业系统工程与管理系；曾于新加坡国立大学和新加坡-麻省理工学院研究中心担任博士后研究员。研究领域为不完全信息下的决策和优化，包括随机占优决策理论、分布鲁棒和风险偏好鲁棒优化问题建模及算法求解、复杂系统建模和优化等。研究成果以第一作者或通讯作者发表在 Management Science、 European Journal of Operational Research、Decision Analysis、Transportation Research Part C: Emerging Technologies、Reliability Engineering & System Safety、 Computers & Operations Research 等国内外管理科学高质量期刊上。主持国家自然科学基金面上和青年项目、浙江省自然科学基金探索一般项目、杭州市哲学社会科学规划重点项目。

英文：Chunling Luo is a Professor and Ph.D. supervisor at Hangzhou Normal University. She received her B.S. degree in Industrial Engineering from Shanghai Jiao Tong University and her Ph.D. degree from the Department of Industrial Systems Engineering and Management at the National University of Singapore. She also worked as a postdoctoral researcher at the National University of Singapore and the Singapore-MIT Alliance for Research and Technology Centre. Her research focuses on decision-making and optimization under incomplete information, including stochastic dominance decision theory, distributionally robust and risk-preference robust optimization modeling and algorithms, as well as complex system modeling and optimization. She has published her work as first author or corresponding author in high-quality international and domestic journals in management science, such as Management Science, European Journal of Operational Research, Decision Analysis, Transportation Research Part C: Emerging Technologies, Reliability Engineering & System Safety, and Computers & Operations Research. She has been the principal investigator of projects funded by the National Natural Science Foundation of China (Regular and Youth Program), the Zhejiang Provincial Natural Science Foundation (Exploration Program), and the Hangzhou Philosophy and Social Sciences Planning Project (Key Project).

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Organizer's Brief Biography

中文：吴温慧，浙江工商大学统计学博士，现为浙江大学伊利诺伊大学厄巴纳香槟校区联合学院博士后研究人员。曾于 2024 年至 2025 年获国家留基委资助赴新加坡国立大学工业系统工程与管理系联合培养一年。主要研究方向包括基于退化数据的可靠性分析与建模、加速寿命试验的统计推断、贝叶斯分析方法。相关研究成果发表于 European Journal of Operational Research、Quality Technology & Quantitative Management 等期刊。

英文：Wenhui Wu received her Ph.D. in Statistics from Zhejiang Gongshang University and is currently a postdoctoral researcher at the ZJU-UIUC Institute, Zhejiang University. From 2024 to 2025, she was supported by the China Scholarship Council to conduct joint research training at the Department of Industrial Systems Engineering and Management, National University of Singapore. Her primary research interests include reliability analysis and modeling based on degradation data, statistical inference in accelerated life testing, and Bayesian analysis methods. Her work has been published in journals such as European Journal of Operational Research and Quality Technology & Quantitative Management.

Session Speakers

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Topic

题目 Title： Inference and Quantification of Cyclostationary Impulses: A novel noise-sensitive mixed Gaussian cyclostationary model for compound fault detection

摘要 Abstract： Rolling bearings are fundamental components in modern industrial systems, where real-time fault diagnosis is vital for enhancing operational safety and optimizing maintenance strategies. Traditional signal demodulation and blind deconvolution techniques are often designed to extract a single cyclostationary impulse with periodic statistics from single fault signals by filtering. However, they cannot provide quantitative confidence levels for diagnosis results, and nonlinear filtering often disrupts multiple local periods on statistics, called the quasi- and pseudo-cyclostationary properties, in handling compound fault signals. This study proposes a novel noise-sensitive mixed Gaussian cyclostationary (MGC) model, designed to model multiple cyclostationary impulses in compound fault signals under noisy conditions. Statistical derivation demonstrates that it can model and demodulate noise- and impulse-coupled systems with probabilistic, additive, and multiplicative coupling. Additionally, a standardized fault diagnosis

process is proposed, using spectral correlation analysis to test the existence of cyclostationary and developing progressive likelihood ratio testing to accurately select the optimal cyclostationary period combinations for MGC modeling and compound fault diagnosis. Without the need to compare with normal signals, the method provides a quantitative statistical confidence level for diagnosis results. Extensive simulations and comparative experiments demonstrate that the method can more accurately extract different cyclostationary impulses from various compound fault combinations.

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Topic

题目 Title: Domain weighted distribution adaptation network: a novel remaining useful life prediction framework for machinery targeting time-varying operation conditions

摘 要 Abstract： Machinery typically operates with condition alternations throughout the degradation process. Commonly used deep learning-based methods for remaining useful life (RUL) prediction primarily focus on degradation under constant operation conditions, including studies that use domain adaptation and similar technologies to predict RULs across different but fixed conditions. However, the lack of training data under time-varying conditions limits the RUL estimation in condition alternation scenarios. To address this issue, this paper proposes a prediction framework targeting time-varying operation conditions, termed the domain weighted distribution adaptation network (DWDAN). It utilizes run-to-failure datasets from constant conditions to predict RULs under time-varying conditions, bridging the gap of prediction between these two scenarios. In the framework, discrepancies in feature distributions are attributed to degradation, operation conditions, and their nonlinear coupling. First, an RUL prediction model is developed using constant condition samples to capture degradation-related distributions. Then, domain weights for different conditions are optimized with normal stage samples from time-varying conditions. Finally, the feature distributions are adjusted via optimal transport (OT) to overcome the nonlinear coupling. The proposed method is validated on experimental run-to-failure datasets of gearboxes. The results demonstrate the superiority of the DWDAN in overcoming the impact of condition alternations and improving prediction performance.

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Topic

题目 Title：The prediction of RULs for gamma k-out-of-n system with nonidentical components based on component data

摘要 Abstract：This paper investigates the prediction procedures of the remaining useful lifetime (RUL) of k-out-of-n system with nonidentical gamma components based on component data. The distributions of the offline and online RULs of system are derived. Using the generalized pivotal quantity and Cornish-Fisher expansion methods, the prediction intervals (PIs) of the offline and online RULs for the gamma k-out-of-n system are derived. In addition, bootstrap PIs of the offline and online RULs for the gamma k-out-of-n system are proposed. The performance of the proposed PIs is assessed in terms of coverage probability by using the Monte Carlo simulation. Finally, a real-data example is used to illustrate the proposed procedures.

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Topic

题目 Title：Nonlinear Stochastic Degradation Modeling of Wax Lubrication Layers with Heterogeneous Covariates

摘要 Abstract：Wax is a commonly used lubricant in many applications. To ensure its security and dependability, degradation analyses for creep are typically conducted. However, challenges arise due to the poorly understood inherent mechanisms of wax and the complicated experimental environment required, leading to nonlinear trends and heterogeneous covariates. In such cases, traditional methods based on parametric forms or linear assumptions may lack the flexibility to capture the complexities and randomness of the degradation process effectively. To address these challenges, we propose a comprehensive degradation analysis framework that employs a Wiener process with an unspecified mean function. By eliminating parametric forms, this approach provides a more versatile method for modeling nonlinear degradation trends. Moreover, it treats environmental covariates as random variables to handle random ecological influences. We develop tailored semiparametric estimators for the model and establish theoretical asymptotic results that guarantee the consistency and convergence of the proposed estimators. A series of numerical experiments is conducted to illustrate the performance of the estimators and validate their convergence properties. The method is applied to a wax lubrication layer, demonstrating its efficacy in analyzing nonlinear degradation data in a random working environment. This work advances the understanding of wax degradation mechanisms and provides a flexible tool for degradation analysis in materials with heterogeneous environments and poorly understood behaviors.

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Topic

题目 Title：Modelling and Estimation for Degradation Data with Initiation-growth Correlations

摘要 Abstract：Influenced by dynamic environmental factors, the degradation rates of products often vary with initial levels. However, most existing degradation models assume a fixed or zero starting point and treat it as independent of subsequent process, leading to biased failure‐time predictions, poorly timed maintenance, and elevated costs or risks. To fill this gap, we propose a Wiener‐process degradation model that explicitly links the random initial phase to its ongoing deterioration, allowing both the degradation rate and the failure threshold to adapt to the initial state. We derive explicit expressions for the lifetime and remaining useful life (RUL) distributions, along with confidence intervals for model parameters. To construct confidence intervals for reliability metrics and prediction intervals for RUL, we propose tailored generalized inference and objective Bayesian inference, which ensure accurate coverage even in small samples. Through comprehensive simulations and a real‐world case study, we demonstrate that our approach more accurately captures individual variability and delivers tighter, more reliable life‐time forecasts than traditional models.