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Belief Propagation for Early Sequential Feature Selection in Manufacturing

Early sequential feature selection is crucial in manufacturing environments with heterogeneous sensors and tightly coupled process variables. In shop-floor applications, predicting End-of-Line test failures using data collected as early as possible is vital to enable timely corrective actions. However, classical feature selection and Explainable Artificial Intelligence methods (e.g., SHAP) evaluate variables globally or independently. Consequently, they often highlight temporally dispersed or late-stage variables as highly predictive, which prevents rapid early interventions.

To address this, we propose a novel Factor Graph topology and an associated Belief Propagation algorithm for early sequential feature selection on classification tasks. The factor graph encodes conditional relationships among candidate features and the target, computing “Influence Scores” to estimate each feature’s marginal. This space is then compressed into a highly informative subset of seven summary statistics.

Evaluated on a Bosch Thermotechnology heat pump production line, our approach restricted the analysis exclusively to an early “Instability Zone”. Our transparent, rule-based classification achieved a Macro F1-Score of 0.750, practically matching the performance of complex Machine Learning models (e.g., XGBoost and Random Forest) trained on the same early zone. Conversely, restricting complex models to the top 10 globally dominant features decreased performance (0.744).

Ultimately, this approach eliminates the need for heavy Machine Learning inference on the shop floor and is adaptable to other continuous manufacturing processes. Furthermore, the proposed model is primed for future Digital Twin integration, projecting a massive time reduction of ≥ 8 hours per failed heat pump.

Special/ Invited session

Classification

Both methodology and application

Keywords

Sequential Feature Selection, Belief Propagation, Factor Graphs, Early Prediction, Predictive Analytics

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Track Classification: AI: Machine Learning and Predictive Analytics