ARULE

PRODUCT BRIEF

Ridgetop Group Inc

ENGINEERING INNOVATION

ARULE™ Prognostic Reasoner

Adaptive Remaining Useful Life Estimator (ARULE™) for PHM Applications

Features and Benefits

- **Dual Capability:** ARULE operates both as a standalone tool for processing historic feature data and as an embedded solution within other software platforms, enhancing them with advanced prognostic capabilities.
- **Powerful Prognostic Engine:** Utilizes advanced prediction algorithms, including extended Kalman filtering, to accurately determine Remaining Useful Life (RUL), State-of-Health (SoH), and Prognostic Horizon (PH).
- **Robust Applications:** Proven effectiveness in diverse systems, including power supply systems, Battery Management Systems (BMSs), actuator controls, and IT networks, ensuring versatility across critical electromechanical systems.
- **Real-Time Predictive Insights:** Offers fast, accurate, and repeatable health estimates, crucial for systems requiring immediate operational decisions.
- **Flexible System Architecture:** Accommodates multiple system nodes and data types, supporting various data sampling and processing methods to handle diverse operational scenarios.

General Description

Our advanced prognostic kernel provides precise analysis of Fault-to-Failure Progression (FFP) signatures, delivering actionable insights into key prognostic parameters, including:

- Remaining Useful Life (RUL)
- State-of- Health (SoH)
- Prognostic Horizon (PH)

Our solution provides precise early warnings, enabling maintenance teams to address issues proactively, reduce downtime, and prevent catastrophic failures—boosting reliability, safety, and efficiency across critical systems.

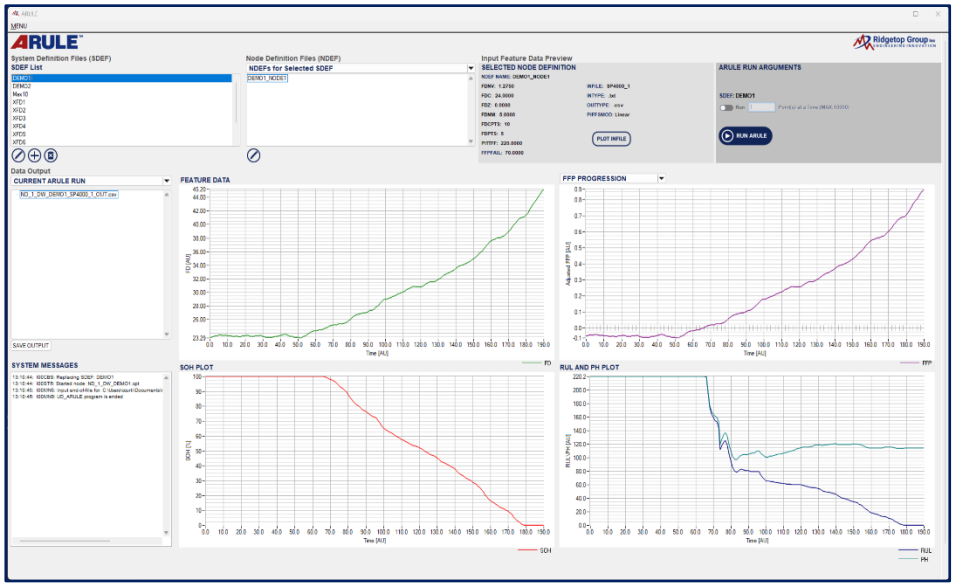

Figure 1 - Example of condition-based data being analyzed with the and mechanical fatigue damage ARULE™ Graphical User Interface (GUI).

ARULE™ is versatile and can be used for determining electrical or degradation. ARULE™ relies on condition-based sensor data and employs an advanced prediction method related to extended Kalman filtering (EKF) to produce new RUL, SoH, and PH estimates for each sensor data point. It requires a sensor to report feature data that are above a predefined “good-as-new” floor and below a “failed” ceiling. A new RUL, SoH, and PH estimate is produced after each data point, and has been proven to have a fast convergence rate to the true time to system failure.

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ARULE™ uses intelligent algorithms that dynamically adapt the RUL according to changes in the level of stress to which the system is subjected. For cases where the level of stress is reduced, ARULE™ recognizes and accounts for evidence of healing in the data. This is shown by an increase in the RUL after acquisition of a certain amount of data that have changed the projection of the RUL estimate. When system degradation resumes, ARULE™ will also show degradation in its RUL, SoH, and PH estimates.

ARULE™ will recognize and apply a degradation progression signature (DPS) that has been derived from an anomaly detection filter, such as one that represents a degraded power supply system. ARULE™ operation, shown to the right in Figure 2 , consists of five steps:

1. Condition-based sensor data are obtained
2. System definition and node definition files are created
3. ARULE™ keywords and parameters are specified
4. Input data files are conditioned and sent to the two-stage prognostic prediction engine to generate prognostic estimates for each data point
5. Data outputs are stored in .txt or .csv format and the results are displayed in the graphical user interface (GUI)

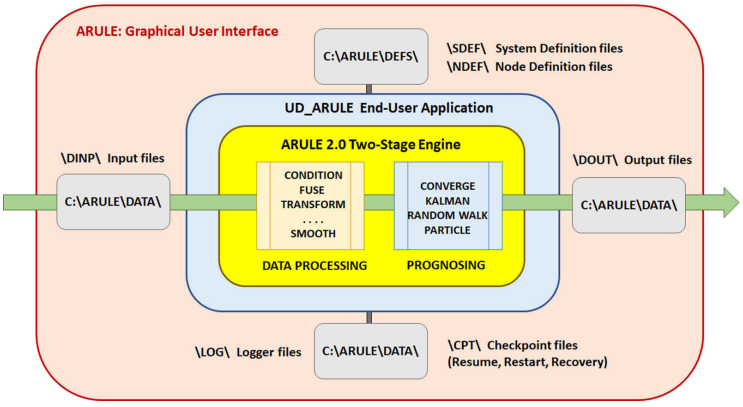

Figure 2 - ARULE™ System Level Diagram

The results provide key information that support Prognostic Health Management (PHM), Condition-based Maintenance (CBM), and Integrated Vehicle Health Management (IVHM) applications.

Open Architecture

ARULE™ uses an open-architecture application programming interface (API) to create definition files, accept input data, and produce prognostic estimates for RUL, SoH, and PH. This API and Ridgetop engineers are available to support the integration into on-board or off- offboard systems and subsystems.

ARULE™ Summary

ARULE™ is an intrinsic component for Ridgetop's Sentinel Suite™ solution, which encompasses sensors, reasoners, and application software modules. Sentinel Power™, Sentinel Motion™, and Sentinel IT™ implement ARULE™ as a reasoner to provide accurate prognostic estimates for RUL, SoH, and PH for a wide variety of applications and use cases.

ARULE™ Applications

- Power Supply Systems
- Power Transmission Systems (Gearboxes)
- Battery Management Systems (BMSs)
- Actuator Control Systems
- Cable Connection Integrity

About Ridgetop Group Inc.

Ridgetop Group is an AS9100D and ISO:9001 certified organization located in Tucson, Arizona. Since its founding in 2000, Ridgetop has specialized in providing best in class CBM, PHM, and reliability engineering solutions to commercial and government organizations to increase safety, efficiency, and operational performance while also reducing maintenance and sustainment costs with the most innovative products and technology.

Our advanced diagnostic and prognostic methods are used to improve test coverage, improve reliability, reduce downtime, and reduce the mean time to repair (MTTR) of mission critical systems. These cost-saving methods are incorporated in products and services have been applied on numerous electromechanical systems and subsystems found in Aerospace, Transportation, Energy, and Industrial applications.

Ridgetop also provides engineering design services for hardware, firmware, and software-based development programs related to the implementation of CBM, PHM, and IVHM strategies.

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