MATLAB EXPO 2019

La maintenance prédictive avec MATLAB et Simulink

Kevin Roblet et Mathieu Cuenant
Corrective Maintenance

Event Criticality

Time

Fault

Corrective Maintenance
Fault

Planned Maintenance

Condition-Based Maintenance

Corrective Maintenance

Event Criticality

Time

Pressure Sensor

Tachometer

Microphone

Condition-Based Maintenance

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Condition indicators

Remaining Useful Life
Digital twin
IOT, data collection
Deployment
Signal-based

- Parameters Estimation
  - Time
  - Frequency
  - Mean, variance, kurtosis…
  - Meanfreq, peaks, powerbw…

Parameters drift
Parameters statistic distribution

Residual Analysis
- Threshold on residuals
- Smallest residual analysis

State Estimators
- Threshold on states
- Abrupt changes

Model-based
Condition Indicators Basics

Condition Indicators for Monitoring, Fault Detection, and Prediction
A condition indicator is any feature of system data whose behavior changes in a predictable way as the system degrades.

Signal-Based Condition Indicators
A signal-based condition indicator is a quantity derived from processing of signal data. The condition indicator captures some feature of the signal that changes as system performance degrades.

Model-Based Condition Indicators
A model-based condition indicator is a quantity derived from fitting system data to a model and performing further processing using the model. The condition indicator captures some feature of the model that changes as system performance degrades.

Condition Indicators in the Diagnostic Feature Designer

Explore Ensemble Data and Compare Features Using Diagnostic Feature Designer
Workflow for interactively exploring and processing ensemble data, designing and ranking features from that data, and exporting data and selected features.

Process Data and Explore Features in Diagnostic Feature Designer
Filter and transform data within the app. Extract features from the imported and derived signals, and assess feature effectiveness.

Interpret Feature Histograms in Diagnostic Feature Designer
Interpret feature histograms to assess how well each feature separates labeled groups of data.

Condition Indicators for Rotating Machinery
Condition Indicators for Gear Condition Monitoring
Workflow to identify condition indicators for gear condition monitoring, and their evaluation.
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Signal-Based Condition Indicators

Featured Examples

- **Rolling Element Bearing Fault Diagnosis**
  Perform fault diagnosis of a rolling element bearing based on acceleration signals. Apply envelope spectrum analysis and spectral

- **Wind Turbine High-Speed Bearing Prognosis**
  Build an exponential degradation model to predict the Remaining Useful Life (RUL) of a wind turbine bearing in real time. The exponential

- **Fault Diagnosis of Centrifugal Pumps Using Residual Analysis**
  Use a model partly-equations-based approach for detection and diagnosis of faults in a pumping system.

- **Analyze and Select Features for Pump Diagnostics**
  Use the Diagnostic Feature Designer app to analyze and select features to diagnose faults in a triplex reciprocating pump.

- **Detect Abrupt System Changes Using Identification Techniques**
  Detect abrupt changes in the behavior of a system using online estimation and automatic data segmentation techniques.

Condition Indicators for Gear Condition Monitoring
Workflow to identify condition indicators for gear condition monitoring, and their evaluation.
Signal-based

Time

Frequency

Parameters Estimation

Residual Analysis

State Estimators

Model-based

mean, variance, kurtosis, …

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abrupt changes
Mathématiques, statistiques et optimisation

Analyse et conception de systèmes de contrôle

Traitement des signaux et communications

Traitement des images et vision industrielle

Test et mesure

Finance computationnelle

Biologie computationnelle

Génération de code

Vérification de code

Déploiement d’applications

Accès aux bases de données et Rapport

Résultats graphiques de simulation et Rapport

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Demo: Analog Input Recorder App
Demo: **Signal Analyzer App**
Demo: Diagnostic Feature Designer App
RUL
Remaining Useful Life

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Estimating the Remainint Useful Life helps predict its time to failure and optimize maintenance schedules.
RUL is based on time evolution of condition indicator

fit($mdl$, $data$)

predict($mdl$, $threshold$)
System Identification

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System Identification

Predictive Maintenance

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Off-the-shelf RUL models

- Run-to-failure history
  - Similarity Models
- Known failure threshold
  - Degradation Models
- Life time data with or without covariates
  - Survival Models
Off-the-shelf RUL models

System Data

Run-to-failure history

Known failure threshold

Degradation Models

Life time data with or without covariates

Survival Models

Similarity Models
Off-the-shelf RUL models: Similarity model
Off-the-shelf RUL models

System Data

- Run-to-failure history
  - Similarity Models
- Known failure threshold
  - Degradation Models
- Life time data with or without covariates
  - Survival Models
Off-the-shelf RUL models: Exponential Degradation model

RUL: 459 hours
(95%CI: 374-558 hours)
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What is a Digital Twin?
Model aiming at being used in operation

Faithful, up-to-date representation of asset

Composite of modeling approaches – data or physics
“Essentially, all models are wrong, but some are useful”

George E.P. Box
Why a Digital Twin?
Prediction

What-If Simulations

Anomaly Detection

Predictive Maintenance
How do I build a Digital Twin?
\[ F_{\text{Spring}} = k \times \text{Mass} \]

\[ F_{\text{Damper}} = b \times \frac{\text{dMass}}{\text{dt}} \]

\[ \frac{\text{d}^2 \text{Mass}}{\text{dt}^2} = -F_{\text{Spring}} - F_{\text{Damper}} \]
Simscape

- Electrical
- Mechanical
- Magnetic
- Thermal
- Custom equations
  
  ```
  if v > V:
    i == (1
  else
  ```

- Hydraulic
- Thermal Liquid
- Two-Phase Fluid
- Gas
- Moist Air
Simscape Component

Block Parameters: Resistor

Resistor
This block represents an ideal resistor

View source for Resistor

Parameters

Resistance: 1 Ohm

equations

v == R * i;

end
The model can be used to *generate training data* for the *machine learning algorithm* and to test the *deployed algorithm*.
Built-in faults

Parameters

Variants

Custom
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Deployment
Actual applications?
Analytic IoT Platform

ThingSpeak™

Smart Connected Devices

Algorithm Development
Billions and Billions
The open data platform for the Internet of Things

Get Started  Contact Us

Collect
Send sensor data to the cloud.

Analyze
Analyze and visualize your data.

Act
Trigger a reaction.
MathWorks can help you get started TODAY

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- **Tech Talk Series**