

Package ‘degradr’

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Type Package

Title Estimating Remaining Useful Life with Linear Mixed Effects Models

Description Provides tools to estimate the Remaining Useful Life (RUL) of degrading systems using linear mixed effects models. Supports both univariate and multivariate degradation signals. For multivariate inputs, signals are fused into a univariate health index prior to modeling. Linear and exponential degradation paths are supported (the latter via a logarithmic transformation). Remaining Life Distributions (RLDs) are computed via Bayesian updating for new units, enabling in-situ predictive maintenance. Based on the methodology of Liu and Huang (2016) <[doi:10.1109/TASE.2014.2349733](https://doi.org/10.1109/TASE.2014.2349733)>.

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Author Pedro Abraham Montoya Calzada [aut, cre, cph] (<<https://orcid.org/0009-0002-3497-210X>>),
Rogelio Salinas Gutiérrez [aut, cph] (<<https://orcid.org/0000-0002-1669-4460>>),

Maintainer Pedro Abraham Montoya Calzada <pedroabraham.montoya@gmail.com>

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Contents

filter_test	2
filter_train	2
fit_healthindex	3
fit_model	5
plot_degradr	6
predict_rul	7
RUL_FD001	8
test_FD001	9
train_FD001	10

Index	12
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 filter_test

Test data for filter degradation and RUL prediction

Description

Test data from a real-world degradation process involving the clogging of gas filters. The dataset includes right-censored lifetimes due to a preventive maintenance policy. Failure is defined when pressure differential exceeds 600 Pa.

Usage

```
data(filter_test)
```

Format

A data frame with 50 degradation trajectories. Variables include:

Time Time

Differential_pressure Differential pressure across the filter in Pascal (Pa).

Data_No Unique identifier for each filter test unit. Integer from 1 to 50.

RUL Remaining Useful Life in hours. Represents the time left until failure (threshold = 600 Pa).

Source

Adapted from:
 Hagemeyer, S., Mauthe, F., & Zeiler, P. (2021). *Creation of Publicly Available Data Sets for Prognostics and Diagnostics Addressing Data Scenarios Relevant to Industrial Applications*. International Journal of Prognostics and Health Management, 12(2). doi:10.36001/ijphm.2021.v12i2.3087

References

See full description in the dataset repository on Kaggle by "Prognostics @ HSE".

 filter_train

Training Data for Filter Degradation and RUL Prediction

Description

Training data from a real-world degradation process involving the clogging of gas filters. The dataset includes right-censored lifetimes due to a preventive maintenance policy. Failure is defined when pressure differential exceeds 600 Pa.

Usage

```
data(filter_train)
```

Format

A data frame with 49 degradation trajectories. Variables include:

Time Time

Differential_pressure Differential pressure across the filter in Pascal (Pa).

Data_No Unique identifier for each filter test unit. Integer from 1 to 50.

Source

Adapted from:

Hagmeyer, S., Mauthe, F., & Zeiler, P. (2021). *Creation of Publicly Available Data Sets for Prognostics and Diagnostics Addressing Data Scenarios Relevant to Industrial Applications*. International Journal of Prognostics and Health Management, 12(2). doi:10.36001/ijphm.2021.v12i2.3087

References

See full description in the dataset repository on Kaggle by "Prognostics @ HSE".

fit_healthindex	<i>Fitting a Health Index Model from Multivariate Signals</i>
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Description

Fits a health index-based degradation model by projecting multivariate sensor signals into a univariate health index and modeling its evolution using a linear mixed-effects model.

Usage

```
fit_healthindex(data,
  type = "exponential",
  method = "nlme",
  degree = 2,
  phi = NULL,
  r = 0.5)
```

Arguments

data	A data frame containing sensor readings over time. Must include the columns t (time), unit (unit identifier), and multiple degradation signals. All degradation signals must have an upward trend.
type	Model type. Either "linear" or "exponential". The exponential model applies a logarithmic transformation to $x - \phi$. Default is "exponential".
method	Estimation method. Either "nlme" to fit a nonlinear mixed-effects model using <code>nlme::lme()</code> , or "lm" to fit separate linear models per unit and estimate fixed and random effects from the set of coefficients. Default is "nlme".
degree	Degree of the polynomial model. Default is 2. The fixed and random effects will include powers of time up to the specified degree.

phi	Initial degradation level for non-defective units. Used in the exponential model as a fixed offset to ensure that the logarithmic transformation is valid and interpretable. If NULL, it is automatically estimated as a value slightly below the minimum observed degradation level. Ignored when type = "linear".
r	parameter that controls the relative importance of the threshold variance and the weighted residual sum of squares in the index-fitted degradation model.

Details

This function implements a two-stage modeling strategy. In the first stage, a univariate health index is constructed as a weighted linear combination of the input signals, using correlation-based shrinkage. In the second stage, the resulting health index is modeled over time with a linear mixed-effects model (on the log scale for exponential models).

The exponential model uses a log transformation of $x - \phi$, where ϕ ensures positivity and interpretability. The ϕ parameter can be supplied by the user or estimated automatically.

The resulting object stores both the projection (health index definition) and the fitted model used for RUL prediction.

Value

Returns an object of class "healthindex", which contains:

index	A list with components: weights w, offset phi, and raw projections.
model	A fitted mixed-effects model of the health index over time.

References

Liu, K. and Huang, S. (2016). *Integration of Data Fusion Methodology and Degradation Modeling Process to Improve Prognostics*. IEEE Transactions on Automation Science and Engineering, 13(1), 344–354.[doi:10.1109/TASE.2014.2349733](https://doi.org/10.1109/TASE.2014.2349733)

Examples

```
library(degradr)
library(dplyr)
# Load example data
data(train_FD001)
data(test_FD001)
data <- train_FD001 %>%
  select(unit,t,T24,T50,P30,
         Nf,Ps30,phi, NRf,
         BPR,htBleed,
         W31, W32) %>%
  mutate(across(c(P30,phi,W31,W32), ~ . * -1))

test <- test_FD001 %>%
  select(unit,t,T24,T50,P30,
         Nf,Ps30,phi, NRf,
         BPR,htBleed,
         W31, W32) %>%
  mutate(across(c(P30,phi,W31,W32), ~ . * -1))

# Fit a health index model (exponential trajectory of degree 2)
model <- fit_healthindex(data = data, type = "exponential",
```

```

                                degree = 2, r = 0.8)
rul <- predict_rul(data = test, model = model)
head(rul)

```

fit_model

Fitting the Linear Mixed Effects Model

Description

Fits a linear or exponential mixed-effects model of degree p for the degradation process.

Usage

```

fit_model(data,
  type = "exponential",
  method = "nlme",
  degree = 2,
  phi = NULL)

```

Arguments

data	A data frame with three columns: <code>t</code> for time, <code>x</code> for the degradation signal, and <code>unit</code> as the unit identifier. At least two distinct units are required.
type	Model type. Either "linear" or "exponential". The exponential model applies a logarithmic transformation to $x - \phi$. Default is "exponential".
method	Estimation method. Either "nlme" to fit a nonlinear mixed-effects model using <code>nlme::lme()</code> , or "lm" to fit separate linear models per unit and estimate fixed and random effects from the set of coefficients. Default is "nlme".
degree	Degree of the polynomial model. Default is 2. The fixed and random effects will include powers of time up to the specified degree.
phi	Initial degradation level for non-defective units. Used in the exponential model as a fixed offset to ensure that the logarithmic transformation is valid and interpretable. If NULL, it is automatically estimated as a value slightly below the minimum observed degradation level. Ignored when <code>type = "linear"</code> .

Details

This function fits a linear or exponential polynomial mixed-effects model of degree p to degradation data collected over time from multiple units. The model captures both fixed effects (population-level degradation trends) and random effects (unit-specific deviations).

The exponential model applies a logarithmic transformation with an offset parameter ϕ . The offset ϕ can be provided or automatically estimated from the data.

At least two distinct units are required to estimate random effects. The degree parameter controls the polynomial order for the time terms in both fixed and random effects.

Value

Returns a list with the estimated model and prior distributions.

References

Liu, K. and Huang, S. (2016). *Integration of Data Fusion Methodology and Degradation Modeling Process to Improve Prognostics*. IEEE Transactions on Automation Science and Engineering, 13(1), 344–354. doi:[10.1109/TASE.2014.2349733](https://doi.org/10.1109/TASE.2014.2349733)

Examples

```
library(degradr)

# Load example data sets
data(filter_train)
data(filter_test)

# Show the original column names
colnames(filter_train)

# Rename the columns to match the expected format: t, x, unit
colnames(filter_train) <- c("t", "x", "unit")
colnames(filter_test) <- c("t", "x", "unit", "RUL")

# Plot the training set
plot_degradr(data = filter_train, D = 600)

# Fit an exponential mixed-effects model of degree 1
model <- fit_model(data = filter_train, type = "exponential", degree = 1)

# Predict the remaining useful life (RUL) for the test units,
# assuming a fixed failure threshold D = 600
predict_rul(data = filter_test, model = model, D = 600)
```

plot_degradr

Plot Degradation Trajectories for Multiple Units

Description

Generates a line plot of degradation signals over time for each unit, optionally overlaying a failure threshold line. This function is useful for visualizing degradation paths across multiple components or systems.

Usage

```
plot_degradr(data, D = NULL)
```

Arguments

data	A data frame with three columns: t for time, x for the degradation signal, and unit as the unit identifier.
D	Optional numeric value indicating the failure threshold.

Details

The function is designed to work with degradation datasets where each row represents an observation of a unit at a particular time. The plot shows how the degradation variable x evolves over time t for each unit. This is especially useful for visual inspection before model fitting or threshold analysis.

Value

Returns a ggplot object that can be further customized or directly printed.

Examples

```
library(degradr)

# Load example data sets
data(filter_train)
data(filter_test)

# Show the original column names
colnames(filter_train)

# Rename the columns to match the expected format: t, x, unit
colnames(filter_train) <- c("t", "x", "unit")
plot_degradr(data = filter_train, D = 600)
```

predict_rul

Predicting Remaining Useful Life (RUL) from Degradation Signals

Description

Estimates the Remaining Useful Life (RUL) for one or more partially observed degradation signals based on a previously fitted linear or exponential mixed-effects model. Returns the posterior RUL distribution for each unit.

Usage

```
predict_rul(data, model, D = NULL, upper = NULL)
```

Arguments

data	A data frame with columns t (time), x (degradation measurement), and unit (unit identifier). Multiple units can be passed simultaneously.
model	An object of class "degradation_model" produced by the fit_model function.
D	(Optional) Critical degradation threshold. If provided, it will be used to compute the RUL via a fixed-threshold model. If NULL (default), a random-threshold model will be used based on training data statistics.
upper	Optional upper bound for the search interval when solving for the quantiles of the RUL distribution. If NULL, the function will use the maximum observed time in the training data.

Details

This function applies Bayesian updating to compute the posterior distribution of the degradation model parameters for each unit, conditional on its observed signal. Then, it computes the Remaining Life Distribution (RLD) and returns quantiles of interest: lower bound, median, and upper bound.

It supports both linear and exponential degradation models, matching the formulation used in [fit_model](#). The posterior updating follows the methodology of Liu and Huang (2016).

Value

A data frame with one row per unit and the following columns:

unit Unit identifier.

RUL Estimated RUL.

References

Liu, K. and Huang, S. (2016). *Integration of Data Fusion Methodology and Degradation Modeling Process to Improve Prognostics*. IEEE Transactions on Automation Science and Engineering, 13(1), 344–354. doi:10.1109/TASE.2014.2349733

Examples

```
library(degradr)

# Load example data sets
data(filter_train)
data(filter_test)

# Show the original column names
colnames(filter_train)

# Rename the columns to match the expected format: t, x, unit
colnames(filter_train) <- c("t", "x", "unit")
colnames(filter_test) <- c("t", "x", "unit", "RUL")

# Plot the training set
plot_degradr(data = filter_train, D = 600)

# Fit an exponential mixed-effects model of degree 1
model <- fit_model(data = filter_train, type = "exponential", degree = 1)

# Predict the remaining useful life (RUL) for the test units,
# assuming a fixed failure threshold D = 600
predict_rul(data = filter_test, model = model, D = 600)
```

RUL_FD001

Remaining Useful Life (RUL) Ground Truth for FD001 Dataset

Description

Ground truth values of the Remaining Useful Life (RUL) for each engine unit in the FD001 subset of the C-MAPSS dataset. These values correspond to the last observed cycle in the test set and are used for evaluation purposes in prognostics models.

Usage

```
data("RUL_FD001")
```

Format

A data frame with 100 observations on the following variable:

RUL Numeric vector indicating the true Remaining Useful Life (in cycles) for each unit in the test set.

Details

This dataset is part of the C-MAPSS (Commercial Modular Aero-Propulsion System Simulation) benchmark and is used as ground truth for performance evaluation of predictive maintenance models, particularly for models estimating Remaining Useful Life (RUL) under the FD001 operating condition scenario.

References

Saxena, A., Goebel, K., Simon, D., & Eklund, N. (2008). *Damage propagation modeling for aircraft engine run-to-failure simulation*. In *2008 International Conference on Prognostics and Health Management* (pp. 1–9). IEEE. doi:[10.1109/PHM.2008.4711414](https://doi.org/10.1109/PHM.2008.4711414)

Examples

```
data(RUL_FD001)
```

test_FD001	<i>NASA Turbofan Engine Degradation Simulation Test Data (Subset FD001)</i>
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Description

Truncated time series data from turbofan engine degradation simulations, generated using the C-MAPSS (Commercial Modular Aero-Propulsion System Simulation) model. This test dataset contains operational sensor data up to a point before failure, intended for validating prognostic algorithms that estimate Remaining Useful Life (RUL).

Format

A data frame with multiple observations (rows) on the following 24 variables (columns):

unit Engine unit number (identifier)
 t Time in cycles
 T2 Total temperature at fan inlet (°R)
 T24 Total temperature at LPC outlet (°R)
 T30 Total temperature at HPC outlet (°R)
 T50 Total temperature at LPT outlet (°R)
 P2 Pressure at fan inlet (psia)
 P15 Total pressure in bypass-duct (psia)

P30 Total pressure at HPC outlet (psia)
 Nf Physical fan speed (rpm)
 Nc Physical core speed (rpm)
 epr Engine pressure ratio (P50/P2)
 Ps30 Static pressure at HPC outlet (psia)
 phi Ratio of fuel flow to Ps30 (pps/psi)
 NRF Corrected fan speed (rpm)
 NRC Corrected core speed (rpm)
 BPR Bypass Ratio
 farB Burner fuel-air ratio
 htBleed Bleed Enthalpy
 Nf_dmd Demanded fan speed (rpm)
 PCNfR_dmd Demanded corrected fan speed (rpm)
 W31 HPT coolant bleed (lbm/s)
 W32 LPT coolant bleed (lbm/s)

Details

Key characteristics of this test dataset:

- Simulates progressive degradation in the High Pressure Compressor (HPC) module
- Time series are truncated prior to failure (true RUL values not included)
- Includes realistic measurement noise and unit-to-unit variability

References

Saxena, A., Goebel, K., Simon, D., & Eklund, N. (2008). *Damage propagation modeling for aircraft engine run-to-failure simulation*. In *2008 International Conference on Prognostics and Health Management* (pp. 1–9). IEEE. doi:10.1109/PHM.2008.4711414

Examples

```
data(test_FD001)
```

train_FD001

NASA Turbofan Engine Degradation Simulation Data (FD001)

Description

Run-to-failure simulation data for aircraft turbofan engines generated using C-MAPSS (Commercial Modular Aero-Propulsion System Simulation). This dataset represents engine degradation in the High Pressure Compressor (HPC) module under varying operational conditions.

Usage

```
data("train_FD001")
```

Format

A data frame with multiple observations (rows) on the following 24 variables (columns):

unit Engine unit number (identifier)
 t Time in cycles
 T2 Total temperature at fan inlet (°R)
 T24 Total temperature at LPC outlet (°R)
 T30 Total temperature at HPC outlet (°R)
 T50 Total temperature at LPT outlet (°R)
 P2 Pressure at fan inlet (psia)
 P15 Total pressure in bypass-duct (psia)
 P30 Total pressure at HPC outlet (psia)
 Nf Physical fan speed (rpm)
 Nc Physical core speed (rpm)
 epr Engine pressure ratio (P50/P2)
 Ps30 Static pressure at HPC outlet (psia)
 phi Ratio of fuel flow to Ps30 (pps/psi)
 NRF Corrected fan speed (rpm)
 NRC Corrected core speed (rpm)
 BPR Bypass Ratio
 farB Burner fuel-air ratio
 htBleed Bleed Enthalpy
 Nf_dmd Demanded fan speed (rpm)
 PCNfR_dmd Demanded corrected fan speed (rpm)
 W31 HPT coolant bleed (lbm/s)
 W32 LPT coolant bleed (lbm/s)

Details

The data was generated for the Prognostics and Health Management (PHM) 2008 data challenge. Each engine unit starts with some initial wear and progresses to failure as efficiency and flow parameters degrade exponentially. The failure criterion is when the health index (calculated from stall margins and EGT) reaches zero. The dataset includes sensor measurements taken at cruise conditions.

References

Saxena, A., Goebel, K., Simon, D., & Eklund, N. (2008). *Damage propagation modeling for aircraft engine run-to-failure simulation*. In *2008 International Conference on Prognostics and Health Management* (pp. 1–9). IEEE. doi:10.1109/PHM.2008.4711414

Examples

```
data(train_FD001)
```

Index

* datasets

RUL_FD001, [8](#)
test_FD001, [9](#)
train_FD001, [10](#)

* models

fit_healthindex, [3](#)

* visualization

plot_degradr, [6](#)

filter_test, [2](#)
filter_train, [2](#)
fit_healthindex, [3](#)
fit_model, [5](#), [7](#), [8](#)

plot_degradr, [6](#)
predict_rul, [7](#)

RUL_FD001, [8](#)

test_FD001, [9](#)
train_FD001, [10](#)