Wind Farm Performance Monitoring with Exploratory Factor Analysis

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Agenda

- Introduction
- About Exploratory Factor Analysis
- EFA applied to wind turbine data
- A monitoring demonstration
- Summary and Outlook
Introduction

Objective:
Robust detection of changes in turbine behaviour

Massive amount of data is collected from each turbine

Proposal: Advanced statistical models
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About Exploratory Factor Analysis

Reduce observed variables to fundamental underlying unobserved variables
\[ X_i = a_1 F_1 + a_2 F_2 + ... a_p F_p + e_i \]

- \( X_i \): \( i \)th observed variable
- \( F_1 \) - \( F_p \): common factors (underlying unobserved variable)
- \( a_1 \) - \( a_p \): loadings
- \( e_i \): not explained by the common factors (error term)
Develop covariance matrix from raw data
No missing values are allowed
Kaiser-Harris criteria to estimate the number of common factors
  (number of eigenvalues of cov. matrix > 0)
Estimate loadings (are not unique)
Rotate matrix (maximize one loading and minimize the others)
  • Maximum likelihood
  • Principal axis
  • (generalized) weighted least square
  • Minimum residual (minimizes the square sum of the off diagonal)
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Choose the variables $X_i$ to be observed:

- Pitch
- Power
- Torque
- Revolution speed
- Wind speed
EFA applied to wind turbine data
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Standardize Observations: $X'_{i} = \frac{X_{i} - \bar{X}_{i}}{S_{i}}$
- minimum residuals (method)
- Oblique: correlation between the Factors has been allowed
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A monitoring demonstration

Turbine Data from different operational modes
To cover the full turbine behaviour, at least five variables are necessary:

- Torque
- Pitch
- Power
- Wind speed
- Revolution speed

Normal operation, Mode 1, and Mode 2 are depicted in different colours.
A monitoring demonstration

The correlation of the two common factors shows clearly a different behavior

- Normal operation
- Mode 1
- Mode 2
EFA applied to wind turbine data

- Normal operation
- Mode 1
- Mode 2
Choosing a smaller sample from the data

No suspicious behaviour visible in this plot
The correlation of the two common factors shows clearly a different behavior but less samples reduce the clarity.
A monitoring demonstration – Wind Farm Scan
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Summary:

- Turbine behaviour can be expressed with two common factors
- Exploratory factor analysis needs a certain sample size
  - With 10 min data, the time to detect changes would be too long
  - Higher frequency data (e.g., 30s data) needs more memory space
  - Factors can be used as statistical summary of high frequency data

Outlook:

- Check minimal sample size
- Check optimal data frequency
Thank you for your attention

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