Hybrid AI for predictive maintenance of wind turbines

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Predictive maintenance

Current condition
Future condition
Effect of initiatives
Industrial reality is complicated

- Complex systems
- Limited standardization
- Data challenges
- Safety critical systems
Complexity of physical/knowledge base

Use of data

Machine learning
Data-driven methods

Hybrid analytics
Combining data-driven and model-based methods

Analytical model
Knowledge/physics-based

High-fidelity simulation
Complex physical model

\[ E = mc^2 \]

\[ F(a) = ma \]
SFI NorwAI

- AI in society
- Thrustworthy AI
- AI for language and personalization

- AI for streaming data
- Hybrid AI analytics
- Data and platforms for AI

ACADEMIC AND RESEARCH PARTNERS
- NTNU
- SINTEF
- NRE
- UiO
- Universitetet i Oslo
- University of Stavanger

INDUSTRIAL, ACADEMIC AND RESEARCH NETWORKS
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- DNB
- SpareBank1 SMN
- Telenor
- Cognite
- Schibsted
- NRK
- Kongsberg
- DNV
- Retriever
- TrønderEnergi
Use cases for Hybrid AI analytics

Virtual flow metering

- **Kongsberg**: Simulated data of AkerBP system
- **Cognite**: Sensor data from AkerBP system

Predictive maintenance for wind turbines

- **DNV-GL**: Simulators of turbines and wind parks
- **TrønderEnergi**: Real data from Skomakerfjellet

Teknologi for et bedre samfunn
Fast surrogate model

Rapid damage equivalent load estimates
Non-linear interpolations between simulations
Uncertainty (interpolation)
Determining fatigue

I. Directly with vibration sensors
II. Without vibration sensors you need simulations
III. Future wear?
Simulate data specific conditions

Data
• Sensor data from turbines

Fatigue

Teknologi for et bedre samfunn
Shortcut with learning surrogates

Data
- Sensor data from turbines

Inference
- Data to parameters

Parameters
- Input parameters for simulation
- With uncertainties

Simulator
- Run with parameters

Simulation
- Condition specific

Fatigue
Shortcut with learning surrogates

- Pros:
  - Trained on pre-run simulations
  - Some frameworks (e.g. Gaussian processes) can give uncertainties

- Cons:
  - No individualisation
  - Requires many simulations
  - Only covers parameter space spanned by simulations
  - No relation to data
Shortcut with learning surrogates

1. **Data**
   - Sensor data from turbines

2. **Inference**
   - Data to parameters

3. **Parameters**
   - Input parameters for simulation
   - With uncertainties

4. **Simulator**
   - Run with parameters

5. **Simulation**
   - Condition specific

6. **Fatigue**

Teknologi for et bedre samfunn
Shortcut with learning surrogates

**Data**
- Sensor data from turbines

**Inference**
- Data to parameters

**Parameters**
- Input parameters for simulation
- With uncertainties

**Pros:**
- Allows for data-defined simulations
- Parameters can be determined with uncertainties

**Cons:**
- Requires many simulations to learn initially
- Only covers parameter space spanned by simulations
- Cannot resolve parameter degeneracies

Teknologi for et bedre samfunn
Shortcut with learning surrogates

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Inference
• Data to parameters

Parameters
• Input parameters for simulation
• With uncertainties

Simulator
• Run with parameters

Simulation
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Fatigue

Teknologi for et bedre samfunn
Summary

I. Large learning potential
II. We need physics
III. Data is crucial
IV. NorwAI work in progress:
   I. Simulation parameter estimation from wind turbine data
   II. Surrogate simulation model
Teknologi for et bedre samfunn