Contrastive Feature Learning for Fault Detection and Diagnostics

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Condition Monitoring Data

Industrial Asset

Monitoring Device: Accelerometer

Monitoring Device: Strain Gauge Sensors & Accelerometers

Monitoring Device: Camera
Factors of Variations in Condition Monitoring Data

<table>
<thead>
<tr>
<th>Controlable Factors</th>
<th>Uncontrolable Factors</th>
<th>Health Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Conditions, New Components, ...</td>
<td>Environmental Factors, ...</td>
<td>Fault Types, Fault Severities, ...</td>
</tr>
<tr>
<td>Different loads</td>
<td>Ambient Temperature</td>
<td>Faults are rare</td>
</tr>
<tr>
<td>Different loads, velocities</td>
<td>Lighting, Background</td>
<td>Fault data not available</td>
</tr>
</tbody>
</table>

Distinguishing these factors can be difficult

Often the available dataset is not representative!
Data-driven fault detection and diagnostics model fail!
Objective

Objective 1:
Invariance to any fluctuation caused by «other» factors

Controlable Factors
Operating Conditions, …

Uncontrolable Factors
Environmental Factors, …

Objective 2:
Sensitivity to Faults

Health Factors
Fault Types & Severities, …
Feature Learning

Objective 1:
Model invariant to “other” factors

Objective 2:
Model sensitive to faults
Contrastive Feature Learning – Triplet Loss

Objective 1:
Model invariant to “other” factors

Objective 2:
Model sensitive to faults

\[ \text{Loss} = \sum_{i=1}^{N} \left[ ||f_i^a - f_p^i||_2^2 - ||f_i^a - f_i^n||_2^2 + \alpha \right]^+ \]
Methodology

Objective 1:
Model invariant to “other” factors

Objective 2:
Model sensitive to faults
Applications

Data Representation

Objective 1:
Model invariant to “other” factors

Objective 2:
Model sensitive to faults
Applications

Objective 1:
Model invariant to “other” factors

Objective 2:
Model sensitive to faults

Limited data from “other” factors
Limited fault data

Sufficient data from “other” factors
All Fault Data Available

Limited data from “other” factors
No Faults Data
Applications

**Objective 1:**
Model invariant to "other" factors

**Objective 2:**
Model sensitive to faults

**Classification**
- Sufficient data from "other" factors
- Limited fault data
- All Fault Data Available

**Difficulty**
- Limited data from "other" factors
- Limited fault data
- No Faults Data
Application 1: Defect Type Classification of Sleepers

Scenario: All fault types known

Objective 1:
Model invariant to “other” factors

Objective 2:
Model sensitive to known faults
Application 1: Defect Type Classification of Sleepers

Scenario: All fault types known

Objective 1: Model invariant to “other” factors

Objective 2: Model sensitive to known faults

Healthy, Cracks, Spalling
Results Application 1: Defect Type Classification of Sleepers

<table>
<thead>
<tr>
<th>Classification</th>
<th>T acc</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLE</td>
<td>81%</td>
</tr>
<tr>
<td>TE</td>
<td>94%</td>
</tr>
</tbody>
</table>

+ 13% accuracy gain
Applications

Objective 1:
Model invariant to “other” factors

Objective 2:
Model sensitive to faults

Classification & Detection

Limited data from «other» factors
Limited fault data

Difficulty

Sufficient data from «other» factors
All Fault Data Available

Limited data from «other» factors
No Faults Data

Limited data from «other» factors
No Faults Data

22.09.2021
Methodology

Objective 1:
Model invariant to “other” factors

Objective 2:
Model sensitive to known and novel faults

Scenario:
Limited data from «other» factors
Limited fault data

Intelligent Maintenance Systems

Train a Feature Encoder Network with $\mathcal{L}^{Triplet}$

Raw Data → Encoder → Feature Space

Evaluate Feature Representation

1) Classification
2) Clustering

SVM
OPTICS
Experiments Conducted on CWRU Dataset (Bearing)

4 Different Operating Conditions (OC - Loads)

Load 0
- Healthy
- Ball Faults
- Severity 1
- Severity 2
- Severity 3
- Inner Race Faults
- Severity 1
- Severity 2
- Severity 3
- Outer Race Faults
- Severity 1
- Severity 2
- Severity 3

Load 1
- Healthy
- Ball Faults
- Severity 1
- Severity 2
- Severity 3
- Inner Race Faults
- Severity 1
- Severity 2
- Severity 3
- Outer Race Faults
- Severity 1
- Severity 2
- Severity 3

Load 2
- Healthy
- Ball Faults
- Severity 1
- Severity 2
- Severity 3
- Inner Race Faults
- Severity 1
- Severity 2
- Severity 3
- Outer Race Faults
- Severity 1
- Severity 2
- Severity 3

Load 3
- Healthy
- Ball Faults
- Severity 1
- Severity 2
- Severity 3
- Inner Race Faults
- Severity 1
- Severity 2
- Severity 3
- Outer Race Faults
- Severity 1
- Severity 2
- Severity 3
Case Studies

Objective 1:
Model invariant to “other” factors

Case Study 1:
Train Models on a subset of the OC

Evaluate Models on
• Known OC
• Novel OC

Load 0  Load 2  Load 3

Load 0  Load 2  Load 3  Load 1

Objective 2:
Model sensitive to known and novel faults

Case Study 2:
Train Models on a subset of the faults

Evaluate Models on
• Known Faults
• Novel Faults
Case Study 1: Classification and Clustering Results on Various Operating Conditions

Objective 1:
Model invariant to "other" factors

Case Study 1:
Train Models on a subset of the OC

Evaluate Models on
• Known OC
• Novel OC

Softer Color represent data recorded under «novel» OC

Compact Class Clusters in the Triplet Encoder feature space despite changing OC

TSNE Plots of the Different Feature Spaces
Classifier Encoder (CLE)
Triplet Encoder (TE)
Case Study 1: Classification and Clustering Results on Various Operating Conditions

Objective 1:
Model invariant to “other” factors

Case Study 1:
Train Models on a subset of the OC

Evaluate Models on
  • Known OC
  • Novel OC

TSNE Plots of the Different Feature Spaces

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<th>Novel OC</th>
<th>Clustering—OPTICS</th>
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<tbody>
<tr>
<td></td>
<td>$\mathcal{T}$</td>
<td>$\mathcal{T}_p$</td>
</tr>
<tr>
<td>acc</td>
<td>$100%$</td>
<td>$99%$</td>
</tr>
<tr>
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Classification and Clustering Results
Case Study 2: Classification and Clustering Results with Novel Faults

**Objective 2:**
Model sensitive to known and novel faults

**Case Study 2:**
Train Models on a subset of the faults

Evaluate Models on
- Known Faults
- Novel Faults

94% of the detected outliers novel faults

**TSNE Plots of the Clustered Feature Spaces**
- Classifier Encoder (CLE)
- Triplet Encoder (TE)
Case Study 2: Classification and Clustering Results with Novel Faults

Objective 2:
Model sensitive to known and novel faults

Case Study 2:

Train Models on a subset of the faults

Evaluate Models on
• Known Faults
• Novel Faults

TSNE Plots of the Clustered Feature Spaces

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<td>T_P</td>
<td>T</td>
</tr>
<tr>
<td>acc</td>
<td>acc</td>
<td>AMI</td>
</tr>
<tr>
<td>CLE</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>TE</td>
<td>100%</td>
<td>0%</td>
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Classification and Clustering Results
Summary & Outlook

Objective 1:
Model invariant to “other” factors

Objective 2:
Model sensitive to faults

Anomaly Detection

Limited data from «other» factors
Limited fault data

Sufficient data from «other» factors
All Fault Data Available

Limited data from «other» factors
No Faults Data
Thank you!