PHM frontiers in Korean manufacturing – success episodes and issues

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Part II: PHM Discipline and Activity

Part III: Successful PHM Episodes

Part IV: Closing Remarks

* PHM: Prognostics and Health Management
Part I
Smart Factory in Korea
Global Manufacturing Competitiveness Index: Country rankings

<table>
<thead>
<tr>
<th>Country</th>
<th>Score</th>
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<tbody>
<tr>
<td>China</td>
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<tr>
<td>United States</td>
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<tr>
<td>Germany</td>
<td>93.9</td>
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<tr>
<td>Japan</td>
<td>80.4</td>
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<tr>
<td>South Korea</td>
<td>76.7</td>
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<tr>
<td>United Kingdom</td>
<td>75.8</td>
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<tr>
<td>Taiwan</td>
<td>72.9</td>
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<tr>
<td>Mexico</td>
<td>69.5</td>
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<tr>
<td>Canada</td>
<td>68.7</td>
</tr>
<tr>
<td>Singapore</td>
<td>68.4</td>
</tr>
</tbody>
</table>

Some Figures of Smart Factory Effort in Korea

Korea Smart Factory Foundation (KOSF) Newly Launched in 2014

- Number: 18 times from ’14 to ’17
- Level: Elementary (76.4%)

<Number of smart factories supported by the KOST Program>

- Elementary: ERP with data acqn.
- Intermediate I: RT equipment data acqn.
- Intermediate II: RT decision making and control

<The level of smart factories in domestic companies>
Outcomes out of Smart Factory Effort in Korea

Improvement of Overall Manufacturing Capability
(2800 companies with smart factory, Dec 2017)

- Productivity: 30% ↑
- Manufacturing Cost: 15% ↓
- Quality: 45% ↑
- Downtime Cost: 16% ↓

Industry 4.0 in Manufacturing

- Process Automation
- Device Monitoring
- Power Control
- IoT
- Big Data Analytics
- Condition Monitoring
- Product Monitoring
- Risk Management
- Life Cycle Management
- Big Data Analytics
- Condition Monitoring
- Product Monitoring
- Risk Management
- Life Cycle Management

Ref: S&T Market Report Vol. 56 2018.02 Smart Factory Industry and Market Trend
Part II
PHM* Discipline and Activity

- PHM Architecture
- Prognostics Solution
- Diagnostics Solution
- Reasoning Solution
- Sensing Solution
- PHM Overview

*PHM – Prognostics and Health Management
Global Recognition of SNU & OnePredict

“Awards

- PEMFC
- Railway Vehicle
- HVAC System
- Pulverizer
- Bogie System

- 2014 IEEE PHM Data Challenge
- 2014 PHM Society Data Challenge
- 2015 PHM Society Data Challenge
- 2017 PHMAP Data Challenge
- 2017 PHM Society Data Challenge

“Five times winner of Global PHM Data Challenges over Various Industrial Sectors”
PHM Standard Architecture (Collab. w/ UNIST, KAU, and Kookmin Univ.)

- **Standard PHM Approaches**

  - Data-driven
  - Rule-based
  - Physics-based

  - Data-driven + Physics-based (Hybrid)
  - Domain Knowledge

- **6 Core Assets in Manufacturing**

  - Driving
  - Power Trans.
  - Power & Energy
  - Machining
  - Hydro-system
  - Electrical & Electronics

- **Standard PHM Procedure**

  1. Raw Data
  2. Cleaning
  3. Organization
  4. Preprocessing
  5. Statistical Modeling
  6. Scaling
  7. Enveloping
  8. Feature Engineering
  9. Health Features
  10. Diagnostics/Prognostics
  11. Health Prediction
### Standard Architecture & MDP* Table for PHM

<table>
<thead>
<tr>
<th>Module</th>
<th>Failure components</th>
<th>Measurement parameters</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>Vibration</td>
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<tr>
<td>Power module</td>
<td>Power supply</td>
<td>D</td>
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<td>Transformer</td>
<td>D</td>
<td>-</td>
</tr>
<tr>
<td>Energy storage system</td>
<td>-</td>
<td>M</td>
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<tr>
<td>Hydraulic module</td>
<td>Cylinder</td>
<td>P</td>
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<tr>
<td>Valve</td>
<td>D</td>
<td>P</td>
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<tr>
<td>PLC</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Inverter</td>
<td>-</td>
<td>D</td>
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<tr>
<td>Switch</td>
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<td>-</td>
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<tr>
<td>Cable</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Diesel module</td>
<td>Motor</td>
<td>M</td>
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<tr>
<td>LM Guide</td>
<td>D</td>
<td>-</td>
</tr>
<tr>
<td>Hydraulic supply</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Reducer</td>
<td>M</td>
<td>-</td>
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<tr>
<td>Transmission module</td>
<td>Ball screw</td>
<td>D</td>
</tr>
<tr>
<td>Chain &amp; Belt</td>
<td>P</td>
<td>-</td>
</tr>
<tr>
<td>Gear</td>
<td>M</td>
<td>-</td>
</tr>
<tr>
<td>Bearing</td>
<td>M</td>
<td>M</td>
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<tr>
<td>Machining module</td>
<td>Machining tool</td>
<td>M</td>
</tr>
<tr>
<td>Electrical tool</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*M: Mature  
D: Developing  
P: Promising

[PHM Standard Architecture](http://onepredict.com/blog/newsView.do)
Part III
Successful PHM Episodes

Case Study 1
Industry Robots

Case Study 2
Industrial Bearing

Case Study 3
Overhead Hoist Transport

Case Study 4
Deep Learning - Steam/Gas Turbine
Industrial Bearing
: Rolling-Element Bearing
REB Failure Prognostics (Schaeffler & Samsung Heavy Industry)

1. Sensing

ISO 10816-1 (Vibration measured on Non-Rotating Parts)

2. Analysis

Waveform analysis
Spectrum analysis
Envelope spectrum & Feature extraction

3. Diagnosis & Prognosis

Prognostic index & RUL Prediction

Industrial Bearings (custom order)

Wind Turbine
Motor

Spindle
Pump & Compressor
Robots
GuardiOne Bearing (Monitoring)

1. Real-time Monitoring of Health Condition
2. Color Image of Health Condition
3. Trend Monitoring of Health Condition
4. Remaining Life Trend Monitoring

“First-ever Commercial Solution for Bearing RUL Prediction”
Steam/Gas Turbine w/ Journal Bearing (Data-driven, Deep Learning)
Deep Learning

Autonomous machine learning algorithms to extract data features through abstraction of massive data sets

Popularity of Deep Learning
- Improved computing power
- Enlarged data size
- Advanced DL techniques

Applications of Deep Learning
- Vision Recognition
- Voice Recognition
- Healthcare
- PHM

Search Trends in Google

• **Data-driven Approach for Feature Learning**

<table>
<thead>
<tr>
<th>Data Acquisition</th>
<th>Feature Extraction</th>
<th>Feature Selection</th>
<th>Feature Learning</th>
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<tbody>
<tr>
<td>Domain Knowledge</td>
<td>Based</td>
<td>Deep Learning</td>
<td>Based</td>
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<tr>
<td>Domain Knowledge</td>
<td>Required</td>
<td>Not Required</td>
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<tr>
<td>System Dependency</td>
<td>Dependent</td>
<td>Independent</td>
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<td>Feature Representation</td>
<td>Shallow</td>
<td></td>
<td>Deep</td>
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<tr>
<td>Big Data Learning</td>
<td>Over-fitted Model</td>
<td></td>
<td>Well-fitted Model</td>
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</tbody>
</table>

- **Deep Learning in PHM**
  - *H. Oh et al. (2017), IEEE Tran. Industrial Electronics*
  - **R. Zhao et al. (2016), IEEE Tran. Neural Networks and Learning Systems (Submitted)**

• **Deep Learning Based Fault Diagnosis**

<table>
<thead>
<tr>
<th>Data Acquisition</th>
<th>Autonomous Feature Engineering by DL</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>DL Type</th>
<th>Input Data Type</th>
<th>Input Data Labels</th>
<th>Others</th>
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<tbody>
<tr>
<td>DBN</td>
<td>n/a</td>
<td>Unsupervised</td>
<td>Break through in deep learning (2006)</td>
</tr>
<tr>
<td>CNN</td>
<td>Vision Data (Images)</td>
<td>Supervised</td>
<td>Parameter sharing, local connectivity</td>
</tr>
<tr>
<td>RNN</td>
<td>Sequential Data (Speech)</td>
<td>Supervised</td>
<td>Storing sequential information</td>
</tr>
<tr>
<td>AE</td>
<td>n/a</td>
<td>Unsupervised</td>
<td>Representation learning, dimension reduction</td>
</tr>
</tbody>
</table>
Deep Learning in PHM

- Deep Learning Algorithms\(^1\)

Deep Belief Network

- RBM 1
- RBM 2
- RBM 3
- RBM 4

Convolutional Neural Network

- 2\(^{nd}\) layer shared weights
- 1\(^{st}\) layer shared weights

Recurrent Neural Network

Auto Encoder

*THE ASIMOV INSTITUTE (http://www.asimovinstitute.org)*
Deep Learning for Steam Turbine

- **GuardiOne Turbine-Deep**

1. **Sensing**

   - **Gap Sensor**
   - **Housing**
   - **Shaft**

2. **Analysis**

   - Omni-directional Regeneration (ODR)

   - **Vibration**

   - **Vib-Imaging Technique**

3. **Scale-free Turbine Prognostics (Fully validated, 92% prediction accuracy)**

   - **Fault Log**
   - **Deep Learning Result**

<table>
<thead>
<tr>
<th>#</th>
<th>Status</th>
<th>Norm.</th>
<th>Rubb.</th>
<th>Misalign.</th>
<th>Oil Whirl</th>
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<tbody>
<tr>
<td>#1</td>
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<td>#5</td>
<td>Rubbing</td>
<td>0.037</td>
<td>0.958</td>
<td>0.005</td>
<td>0.001</td>
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Part IV
Closing Remarks
“Industrial Information is the one with industrial value, which includes availability, quality, productivity, energy efficiency, safety, etc.”
Issues in PHM

Data Quality
Missing, Unsynchronized, Noisy Data

Lack of Labeled Data
Class Imbalance, Labeling Quality

Lack of Resources
PHM Experts, Budgets

Cyber Security & Data Ownership
Protection of Cloud Network Information
THANK YOU FOR LISTENING
ANY QUESTION?