PHM for Manufacturing Industry with IoT and Cloud Platform

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UNIST
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PHM Status on Current Factory Floor

• PHM (Prognostics and Health Management)
  • Machinery-dependent PHM
    – Installed as the machinery is designed
  • Centralized data center for PHM
    – Inefficiency in data management
  • PHM only available for core components
    – Maintenance not available for many of the equipment
  • Snapshot data acquisition
    – No historical data considered
  • Decision-making based on thresholds
    – Low accuracy for PHM results
PHM for Smart Factory

• Increased factory complexity and diverse productions
  – Increase in loss cost due to unforeseen failures and accidents
  – Increased importance of the equipment maintenance field

• Importance of managing factory data (massive data)

• The advent of the Smart Factory
  – Need for new communications and computing technology
    • Internet of Things (IoT) and Cloud Computing
  – Lead to changes in PHM
Internet of Things (IoT)

- Technology that connects all sorts of things (Embedded Systems) to the Internet

- Connection network between things forming an intelligent network for sensing, networking, and data processing
  - **Sensing Technology**
  - Wire-wireless communication and network infrastructure technology
  - IoT service interface technology

- Sensors can be equipped for data acquisition
  - Acceleration, gyro, camera, temperature, etc.

- Applicability of PHM on factory floor
Cloud Computing

• Internet-based computing technology
  – Web based-software service where the program is set within the Internet utility data server and executed only when used
  – On-demand Computing
  – Reduction in system management costs

• Cloud Platform
  – Set of technologies and toolset that are needed when developers create applications that are run within the cloud or utilize the services provided by the cloud
  – Server construction possible with low cost and manpower
  – Services provided by companies such as IBM, Google, and Amazon

<table>
<thead>
<tr>
<th>IBM</th>
<th>Google</th>
<th>Amazon</th>
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<tbody>
<tr>
<td><img src="image" alt="IBM Bluemix" /></td>
<td><img src="image" alt="Google Cloud Platform" /></td>
<td><img src="image" alt="Amazon web services" /></td>
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</tbody>
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PHM with IoT and Cloud Platform

• Prognostic Health Management (PHM)
  – Short-term Analysis
    • IoT Sensors
    • Local
    • Analysis of current health
    • Fault mode classification
  – Long-term Analysis
    • Cloud Computing
    • Integrated
    • Trend analysis based on utilization of accumulated data
    • Time series and causality analysis

• Display Dashboard
  – Data Visualization
    • Intuitive Information
    • Interactive Information
  – Web-based Service
IoT Sensors

- **IoT system composition**
  - Wi-fi microcontroller
  - IMU accelerometer
  - Li-Ion battery

- **Acquisition of Training Set**
  - Rotor testbed made by Signallink Inc.

<table>
<thead>
<tr>
<th>Image</th>
<th>Specifications</th>
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</thead>
<tbody>
<tr>
<td>Particle Photon</td>
<td>Broadcom BCM43362 Wi-Fi chip STM32F205 120Mhz ARM Cortex M3 1MB flash, 128KB RAM <a href="https://store.particle.io/">https://store.particle.io/</a></td>
</tr>
<tr>
<td>IMU Sensor</td>
<td>3 acceleration channels 16-bit data output 1 kHz Sample Rate <a href="https://www.sparkfun.com">https://www.sparkfun.com</a></td>
</tr>
</tbody>
</table>

* Wi-fi Communication Maximum Speed : 11 MBit/s

<table>
<thead>
<tr>
<th>Rotor Testbed</th>
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<tbody>
<tr>
<td>RPM</td>
<td>1500</td>
</tr>
<tr>
<td>Fault Mode</td>
<td>Normal</td>
</tr>
<tr>
<td>Sensor Position</td>
<td>Bearing Housing</td>
</tr>
<tr>
<td>Sensor</td>
<td>X-axis accelerometer</td>
</tr>
<tr>
<td>Sample Rate</td>
<td>1 kHz</td>
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</table>
Machine Learning for PHM Algorithm

• Generate Feature Space
  – Feature: 1X Amplitude, 2X Amplitude

• Linear classification for non-linear data
  – Kernel Trick
  – Radial Basis Function (RBF) Kernel

\[ K(x, x') = \exp \left( -\frac{\|x - x'\|^2}{2\sigma^2} \right) \]

Data becomes linear separable in high-dimensional space
Machine Learning for PHM Algorithm

- Logistic Regression for multi-classes
  - Multi-class classification
  - Using softmax function

\[
P(y = j \mid x^{(i)}) = \frac{\exp(\theta_j^T x^{(i)})}{\sum_{k=1}^{k} \exp(\theta_j^T x^{(i)})} \quad j : \text{class} \\
\sum_{k=1}^{k} \exp(\theta_j^T x^{(i)}) \quad k : \text{class number} \\
\sum_{l=1}^{l} \exp(\theta_j^T x^{(i)}) \quad x : \text{feature vector}
\]

- Optimization

\[
\min_{\theta} J(\theta)
\]
IoT Sensor with Machine Learning Embedded

- Algorithm embedded (C++)
  - Feature Extraction Function
  - Classification model

- Real-time data processing

- Data Acquisition
- FFT
- RBF Kernel
- Logistic Regression

- Feature Vector
  - 1X Amplitude
  - 2X Amplitude

- Probability of Machine State
IOT-based PHM Framework

**IoT with Machine Learning**
- Data Acquisition
- FFT
- RBF Kernel
- Logistic Regression

**Cloud Platform**
- Web-based Service
- Data Visualization

**Data compression**
- Feature Vector
  - 1X Amplitude
  - 2X Amplitude
- Probability of Machine State

Not raw data, but health information
Web-based Dashboard

• Web based service using Cloud Server
  – Accessible with mobile devices or computers
• Feature Information
• Probability of Machine state
Demo
Demo: Normal

iSystems Design Lab: Rotating machinery monitoring

Device: 00F8:80:DE28

Sensors
- 2X Amplitude
- 1X Amplitude
- Misalignment
- Unbalance
- Normal

Graphs showing normal, misalignment, and unbalance conditions.
Demo: Normal
Unbalance

misalignment

unbalance

normal
Misalignment
Conclusion

• Build sensors based on IoT and machine learning algorithms
  – Wire-less data acquisition
  – Feature Extraction
  – Non-linear and multi-class classification
  – Short-term Analysis

• Utilize Cloud Platform

• Future plans
  – Implementation of long-term analyses utilizing cloud resources
    • Trend analysis of machinery using time data
    • Causality analysis of machinery based on accumulated diagnosis data
  – Machinery diagnosis based on sensor networks
    • Diagnosis algorithm using multiple IoT sensors
    • Comparison and combination of data between machinery