Industrial Big Data Analytics and CPS for Smart Sport Manufacturing

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Outline

► IoT New Thinking on Visible and Invisible Opportunities

► Industrial Big Data Analytics and Cyber-Physical Systems (CPS), & Industry 4.0

► Predictive Analytics for Smarter Industrial/Manufacturing Systems and Dominant Innovation® and Business Transformation Case Studies

► Conclusions
Global Industry Partners (80+)

**CANADA**
- SNC-Lavalin
- Ford
- Intel
- Caterpillar
- BorgWarner
- Monsanto
- Chrysler
- Harley-Davidson
- Johnson Controls
- Sarnia Chemicals

**Germany**
- FORCAM
- Bosch/Rexroth
- Siemens
- Festo

**Belgium**
- FMTC

**Finland**
- Kone

**France**
- Alstom
- Michelin
- EADS

**Spain**
- Tekniker

**USA**
- P&G
- NI
- Parker
- Goodyear
- GE Aviation
- Woodward
- API
- GCWW
- Applied Materials (2)
- LAM Research
- TI
- Micron
- Carrig
- Raytheon
- Emerson
- P&W Canada
- Intel
- Toyota
- TechSolv
- Idaho Nat. Lab
- Ingersoll Rand
- Spirit Aerosystems
- Eaton
- Kistler

**China**
- Shaanxi Heavey Truck
- China State Ship Co.
- Hava Zhong NC
- SANY
- Shaanxi Heavy Truck
- Hua Zhong NC
- Shanghai Electric
- Boeing
- Johnson Controls
- Cox
- Toyota
- Intel
- Caterpillar
- BorgWarner
- Montronix
- Daimler-Chrysler
- Harley-Davidson
- General Electric
- Genex
- Toyota
- Intel
- United Technologies
- Rockwell
- Siemens TTB
- Siemens
- Bosch
- Prometec
- EDAptive
- Genex
- Toyota
- Intel
- United Technologies
- Rockwell
- Siemens TTB
- Siemens
- Bosch

**Japan**
- Denso
- Omron Corporation
- Nissan
- Hitachi
- Komatsu
- Mitsubishi Heavy Industries
- Toshiba Corporation

**Taiwan**
- HIWIN
- Cosen
- III
- PMC
- NTU
- Servtech
- KIMPO
- Advantech
- MIRDC
- ITRI
- Delta Electronics
- Tongtai Machine Tool

**Legend:**
- Active Member
- Past Member
Enhanced Six-Sigma Design

- Product Center
- Product Redesign
- Smart Design

Closed-Loop Life Cycle Design
- Design for Reliability and Serviceability

Just-in-Time Service
- Near "0" Downtime

Health Monitoring Sensors & Embedded XYZ/Connected XYZ

Watchdog Agent® Degradation Assessment (Machine Feature Monitoring)
- Self-Maintenance
  - Redundancy
  - Active
  - Passive

Communications
- TetherFree (Bluetooth)
- Internet
- TCP/IP

Health Information

Smart Infotronics (Twin-Model)
- Decision Support Tools for Maintenance Scheduling
- Asset Optimization Predictive and Prescriptive Analytics

Self-Maintenance
- Redundancy
- Active
- Passive

NSF I/UCRC IMS Vision in 2000

IMS Vision in 2000

GE Industrial Internet System

IMM Adventure in 2001 → Catalyst → GE Venture in 2011

Physical and Human Networks

Intelligence flows back into machines

Instrumented Industrial Machine

Extraction and storage of proprietary machine data stream

Secure, Cloud-Based Network

Data sharing with the right people and machines

Remote and Centralized Data Visualization

Big Data Analytics

Ref: GE Industrial Internet

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GE 4th Minds + Machines, Sept. 30, 2015

Industrial Internet and Next GE

Zero Downtime

Digital Twin

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Role of Industrial Big Data

Problems

Data

Knowledge & Experiences

Experiences-based → Evidence-Based

Big Data & Transformation Opportunities

Utilize New Knowledge/Technologies For Value-added Improvement

Value Creation using Smarter Information For Unknown Knowledge

Problem Solving Through Continuous Improvement and Standard Work

5S → Surprise

Utilize New Methods/Techniques to Solve The Unknown Problems

Visible

Invisible

Avoid

Solve
Industrial Big Data in 1990s

► GM OnStar®
► UTC Otis Elevator REM®
► GE Medical InSite®

Industrial Big Data in 2000s

► John Deere Agir Service® 2002
► Komatsu Komtrax® 2002-2005
► GE Aviation OnWing Support® 2005
► Alstom Train Tracer® 2006
► Goodyear FuelMax® 2008
# Product/Manufacturing Evolution

**Avoid**
- Smart Sensors & Prognostics and Health Mgt
- GE Power By the Hour
- On-Wing Support
- Komatsu Komtrax

**Solve**
- Improved Productivity/Lean Manufacturing
- Improved Product Design
- GE Aviation
- John Deere Agri Service
- Goodyear Smart Tire

**Visible**

**Invisible**

- Cyber-Physical Systems & Industry 4.0 in Manufacturing (Self-Configure & Resilient Machine)
- Predictive Healthcare (Genetic Test and Analytics, Molecular Medicine)

**Predictive Big Data Analytics**

- Self-Configure & Resilient Machine
- Genetic Test and Analytics
- Molecular Medicine

## Outline

- **IoT New Thinking on Visible and Invisible Opportunities**
- **Industrial Big Data Analytics and Cyber-Physical Systems (CPS)**
  - Predictive Analytics for Smarter Industrial/Manufacturing Systems and Dominant Innovation® and Business Transformation Case Studies
- **Conclusions**
Value of Predictive Analytics

► Apply Data Analytics to large amounts of data of a variety of types to uncover hidden patterns, unknown correlations and other useful information from industrial and manufacturing systems and integrate with business automation software for improved productivity and innovation.

Data Analytics

Data Analytics is the scientific process of transforming data into insight for making better decisions.

1. Descriptive Analytics: data queries, descriptive statistics, and data visualization

2. Prescriptive Analytics: simulation, decision analysis, and optimization.

3. Predictive Analytics: forecasting, predictive modeling, data mining, machine learning, support vector machines, etc.
Predictive Analytics and Big Data

Start of Performance Degradation

Normal Behavior

Current Situation

Model of Failure

Predicted Probability of Failure

Predicted Confidence Value

Predicted Uncertainties

Evolution of ARMA Prediction

ARMA Prediction

Watchdog Agent® → Machine Analytics

Sensor Data

Vibration

Current

Acoustic

Temperature

Metrology Data

Before Errors Happen

Regularly Inspect

Act

Data to Machine, Machine to Machine, Machine to Factory, Factory to People and SCM

Brilliant Manufacturing (GE)

Data Acquisition

Signal Processing

Feature Extraction &

Health Assessment

Logistic Regression

Statistical Pattern Recognition

Feature Map

Pattern Matching (Self-organizing Maps)

Neural Network

Gaussian Mixture Model (GMM)

Health Diagnosis

Support Vector Machine (SVM)

Feature Map

Pattern Matching (Self-organizing Maps)

Bayesian Belief Network (BBN)

Hidden Markov Model (HMM)

Performance Prediction

Autoregressive Moving Average (ARMA)

Elman Recurrent Neural Network

Fuzzy Logic

Match Matrix

Risk Radar Chart

Degradation (Confidence Value)

Health Map

Data to Machine, Machine to Machine, Machine to Factory, Factory to People and SCM

Brilliant Manufacturing (GE)

Each

Info-graphics


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Challenges of Industrial Big Data

1. Broken

2. Bad

3. Background


What are Cyber-Physical Systems?

► Physical
    – natural and human-made systems governed by the laws of physics and operating in continuous time

► Cyber – computation, communication, and control that are discrete, logical, and switched

► Cyber-Physical Systems – systems in which the cyber and physical components are tightly integrated at all scales and levels

Ref: NSF CPS Program, 2007
Cyber-Physical Machine Systems

Cyber Space

- PHM Apps
- Module-Based Controller “App Store”

Physical Space

- External Sensors
- Machine Self-Awareness

Closed-Loop Feedback

Data Analytics

Internal:
- Controller

External:
- Sensors

Architectures for 5 Levels (5C) of CPS

V. Configuration Level
- Self-configure for resilience
- Self-adjust for variation
- Self-optimize for disturbance

IV. Cognition Level
- Integrated simulation and synthesis
- Remote visualization for humans
- Collaborative diagnostics and decision making

III. Cyber Level
- Twin model for components and machines
- Time machine for variation identification and memory
- Clustering for similarity in data mining

II. Data-to-Information Conversion Level
- Smart analytics for
- Component machine health
- Multi-dimensional data correlation
- Degradation and performance prediction

I. Smart Connection Level
- Plug & Play
- Tether-free communication
- Sensor network

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### Prognostics-Ready Edge Computing

**Advanced algorithms for:**
- Peer-to-peer monitoring
- Time-machine snapshots
- Collaborative diagnosis
- Decision optimization

**User Interface**
- Data visualization
- Data management
- Remote configure of cloud and PHM box

**PHM-ready Smart Cyber Box:**
- IoT Connect and FCFT
- Knowledge-based feature extraction
- Reconfigurable machine-based
  - Analysis

**Time-Machine Snapshots**

**IMS Cloud**

- PHM dedicated features instead of raw data
- Integration of various data source
- Ready-to-use structural data format

**Controller data Add-on sensors**

**PHM-Ready Smart BOX**

**Supervisory Control**

**Required Actions**

**Resilient Control System (RCS)**

**Actions to Avoid**

**Decision Support System (DSS)**

**Prioritize and Optimize Decisions**

**Cyber-Physical Systems (CPS)**

**Self-Compare**

**Self-Aware**

**Condition Based Monitoring (CBM)**

**Condition Monitoring**

**Effective Sensor Selection**

**Configuration**

**Cognition**

**Cyber**

**Conversion**

**Connection**

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**5C Platform for Predictive Analytics and CPS**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Supervisory Control</th>
<th>Required Actions</th>
<th>Resilient Control System (RCS)</th>
<th>Actions to Avoid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognition</td>
<td></td>
<td></td>
<td>Decision Support System (DSS)</td>
<td>Prioritize and Optimize Decisions</td>
</tr>
<tr>
<td>Cyber</td>
<td>Fleet of Machines</td>
<td>Peer to Peer Monitoring</td>
<td>Cyber-Physical Systems (CPS)</td>
<td>Self-Compare</td>
</tr>
<tr>
<td>Conversion</td>
<td>Machines</td>
<td></td>
<td>Prognostics and Health Management (PHM)</td>
<td>Self-Aware</td>
</tr>
<tr>
<td>Connection</td>
<td>Components</td>
<td></td>
<td>Condition Based Monitoring (CBM)</td>
<td>Condition Monitoring</td>
</tr>
</tbody>
</table>

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**The Watchdog Agent® Tools**

- PHM-Ready Smart Cyber Box

**Prognostics-Ready Edge Computing**

- IMS Cloud
-watchdogagent®

**Advanced algorithms for:**
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- Time-machine snapshots
- Collaborative diagnosis
- Decision optimization

**User Interface**

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**PHM-ready Smart Cyber Box:**

- IoT Connect and FCFT
- Knowledge-based feature extraction
- Reconfigurable machine-based

**Controller data Add-on sensors**

**PHM-Ready Smart BOX**
## Comparison of Industry 4.0 Factory vs. Today’s Factory

<table>
<thead>
<tr>
<th>Component</th>
<th>Today Factory</th>
<th>Industry 4.0 Factory</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Source</strong></td>
<td>Attributes</td>
<td>Key Technologies</td>
</tr>
<tr>
<td><strong>Component</strong></td>
<td>Sensor</td>
<td>Precision</td>
</tr>
<tr>
<td><strong>Machine</strong></td>
<td>Controller</td>
<td>Quality &amp; Performance</td>
</tr>
<tr>
<td><strong>Production Systems</strong></td>
<td>Networked Systems</td>
<td>Efficiency &amp; Productivity</td>
</tr>
</tbody>
</table>

### Attributes
- Self-Aware
- Degradation
- Self-Predict
- Self-Compare
- Health
- Prognostics
- Self-Reconfigure
- Self-Optimize
- Worry-Free
- Production

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### 6M System in Manufacturing

1. **Materials** – Property, Strengths, Functions
2. **Machine** – Precision, Capabilities, Automation
3. **Methods** – Tools, Analytics, knowhow
4. **Measurement** – Understand Issues and Improve
5. **Maintenance** – Monitor, Prevent, and Avoid
6. **Models** – Predict, Optimize, and Resilient (Cyber-Physical Systems) → Industry 4.0

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Jay Lee, Germany Harting Tech New 26, 2013

Jay Lee, Industrial Big Data, 2015
6Cs in Big Data System

1. Connection -- RFID, Wireless, Sensors, IoT
2. Cloud – Computing and Data on Demand
3. Cyber— Model and Memory
4. Content/Context – Correlation and Classification
5. Community -- Relationship and Sharing
6. Customization – Service and Value

Jay Lee, Industrial Big Data, 2015

New Manufacturing Value Creation Model

Value Creation using Big Data Analytics

Core Manufacturing

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Robot Health Monitoring
Nissan Manufacturing Plant
Smyrna, Tennessee
Networked Robot Health

1. Collect data from robots
2. Store data in Nissan Server
3. Convert data to ROBOT HEALTH INFORMATION (IMS)
4. Plan maintenance & production

Fleet-based Health Monitoring Technique (2012)

The objective is to group similar machines for sound comparison during fault detection.

Case Study: Robotic Arm Monitoring

Performance Benchmarking with Independent Model:

Space of Improvement: Dynamic Clustering

Applying the IMS logistic regression algorithm included using the moving average and RMS torque value of the low-speed regime segmented data set as the two features used in training the model using the unacceptable (degraded) state data and acceptable (healthy) state data.

The results of applying this method for the third robot joint servo motor are shown above, which shows that early signs of degradation can be seen as early as 3 weeks in testing cycle 125 but failure does not actually occur until cycle 220.
Factory Sentinel – Robot Health Map

IMS Demonstration APP

List of Machines in factory plant with abstract information about each machine including: working status, Latest health value and last timestamp of historical data
By clicking on each machine, detailed information of that machine will be displayed.
In the first section (overview) a radar chart for overall health status of machine components is displayed.

In components section, CV curve for each component will be displayed.
User can select desired component to view its CV curve.
6Fs in Textile and Fabrics

1. Fulfill – Wear, Worm, and Work

2. Fashion – Wear for Style (materials, design, and color)

3. Fit – Customization and Personal Fit (sports)

4. Feel—Wear with Comfort and Flexibility (sports)

5. Functional – Special Mission and Needs (medical, harsh environment, cosmetics, etc)

6. Fun – Wearable Pro

Smart Wearable Systems for Sports and Peer-to-Peer Personal Healthcare
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Transformation

Visible ➤ Invisible
Solve ➤ Avoid
Data ➤ Analytics
Product ➤ Value
Experience ➤ Evidence
IMS Major Impacts

1. IMS is the "Catalyst" of Industrial Internet and Digital Twin Technologies.

2. Ranked the highest Economic Impacts (1:270) by NSF Economic Impact Study Report in 2012.


NI LabVIEW Watchdog Agent® Toolkit

Gray icons are LabVIEW built-in functions
工业大数据新書, July 2015

3/26/16 Published in Japan
Thank You!

www.imscenter.net

Google Jay Lee, Prognostics, E-Manufacturing, E-Maintenance, Dominant Innovation, Cyber-Physical Systems