Cloud-Based Prognosis
Remote Monitoring and Control
for CPS

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Presentation Outline

- **Cloud-Based Prognosis for Smart Manufacturing**
- **Remote Monitoring and Control**
- **Challenges and Opportunities in CPS**
- **Summary**
Definition

Forecasting the likely outcome of a situation

- Disease/Epidemiology
- Weather forecasting
- Economic development

Originally a medical term back in the 19th century:

- Main aim was not to cure disease, but to give a medical diagnosis and predict the patient's chance of survival in terms of remaining life;
- Focus shifted only decades later to curing disease.
In the Context of Manufacturing

- Predict expected *progression* of degradation in a machine or its components from its *current* state to *future* functional *failure*, and the *confidence* associated with prediction;

- Identify short-term and long-term actions/decisions to improve *remaining useful life* (RUL) of a machine;

- Provide scientific and technical basis for *maintenance* scheduling, asset management, and effective *decision* making.
**Need for Prognosis**

- **Trade-off analysis:** cost of maintenance vs. reliability of machines
- Reduce maintenance cost caused by repair-induced failures or unnecessary part replacement

Example of Model-Based Prognosis

- Use **probability** distribution for model formulation.
- **State evolution** model and **measurement** model link sensor output with underlying machine states.
- Machine state: inferred given new measurements, by estimating the posterior **PDF (probability density function)** based on **Bayes’ rule**.
- Can evaluate uncertainty due to measurement noise, when quantifying key measures, e.g., accuracy, precision, and confidence.

I4.0 and Cloud Can Help
Industry 4.0

1. Industrial revolution
   Follows introduction of water- and steam-powered mechanical manufacturing facilities
   End of 18th century

2. Industrial revolution
   Follows introduction of electrically-powered mass production based on the division of labour
   Start of 20th century

3. Industrial revolution
   Uses electronics and IT to achieve further automation of manufacturing
   Start of 1970s

4. Industrial revolution
   Based on Cyber-Physical Systems
   Today

First mechanical loom
1784

First production line, Cincinnati slaughterhouses
1870

First programmable logic controller (PLC), Modicon 084
1969

Source: DFKI 2011
Smart Manufacturing / Factories

Cyber-Physical Systems
Industrial Internet
Smart
Big Data
Internet of Things
Cloud Manufacturing
Manufacturing
Embedded Systems
System of CPS
Service Levels in the Cloud

Typical computing applications
- Applications
- Data
- Runtime
- Middleware
- O/S
- Virtualisation
- Servers
- Storage
- Networking

Infrastructure (as a Service)
- Applications
- Data
- Runtime
- Middleware
- O/S
- Virtualisation
- Servers
- Storage
- Networking

Platform (as a Service)
- Applications
- Data
- Runtime
- Middleware
- O/S
- Virtualisation
- Servers
- Storage
- Networking

Software (as a Service)
- Applications
- Data
- Runtime
- Middleware
- O/S
- Virtualisation
- Servers
- Storage
- Networking

Managed by vendor

You manage
Cloud Manufacturing vs. CPS

“is an integrated cyber-physical system that can provide on-demand manufacturing services digitally and physically to best utilise manufacturing resources.”

Positioning of Cloud Prognosis

- Deterministic physics-based methods
- Probabilistic physics-based methods
- Probabilistic data-driven methods
- Deterministic data-driven methods

Data Analysis & Prognosis

Condition-Based Monitoring

- Vibration signals
- Force, current signals
- Machine status
- Machine usage data
- Abnormal events

Cloud-Enabled Prognosis

- Connectivity to networked machines
- Real-time machine usage data acquisition

Predictive Maintenance

- Advance warning
- Usage adjustment
- Maintenance planning
- Maintenance action
- Least machine downtime

Smart Sensing

- Connectivity to networked machines
- Real-time machine usage data acquisition

Distributed and Heterogeneous Manufacturing Machines

Cyber

Sensor Data

Physical

RUL Prediction

Advances in data analysis and cloud-enabled prognostics enable condition-based monitoring and predictive maintenance, thereby enhancing the efficiency and reliability of manufacturing processes.
Architecture for Cloud Prognosis
Benefits:

- Improved **accessibility** and **robustness**: offering integrated solution to configurable and pay-as-you-go prognostic services;

- Better **collaboration** and **distribution**: benefits from information sharing and fusion realised by crowdsourcing;

- Improved **computational efficiency** and data storage.
Related Activities – Mainly in Europe

R&D Activities


- Internet Based Diagnosis – CIRP Annals, 2001
- Cyber Workspace – Communications of ACM, 2002
- Wise-ShopFloor – ASME JCISE, 2004
- IRMOS – EU FP7 Project, 2007
- Remote Maintenance – CIRP Annals, 2008
- Remote Monitoring – CIRP Annals, 2011
- CAPP-4-SMEs – EU FP7, 2012

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Remote Condition Monitoring
Camera-Less Remote Monitoring

- Java 3D uses scene graphs to represent models.
- A scene graph must have a virtual universe as a base to hold graphical components.
- It may have many branches.

- Three scene graph branches are used to generate a Wise-ShopFloor.
A Mini Robotic Assembly Cell

Virtual Universe

- Lights
- Background
- Viewpoint Control
- Base Platform
- Joint-1 Behaviour Control
- Joint-1
- Joints 2-5
- Gripper Behaviour Control
- Gripper

Behaviour node
TransformGroup node
BranchGroup node
User defined codes
Geometry
Appearance

A mini robotic assembly cell
Application 1: Asset Monitoring

Wise-ShopFloor
## Data Size Comparison

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<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative position of 6 joints</td>
<td>Absolute position of 6 joints</td>
<td>CW</td>
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- **0.017%**

### Images

**An 8-bit VGA Camera Image**
- 640×480 (307,200 bytes)

**One Scene in Java 3D**
- Any size (52 bytes)
Application 2: Cloud-Based M/M

1. Operation History
2. Remote Maintenance
3. Software Input/output


Application 3: Our Prototype

Prognosis Application Framework

Component of Interest
Available Data
Available Methods
Method Selection
Modelling
Training Data Sets
Prognosis
Decision Making

Domain Ontologies Repository

Services Management Platform

Local RDBs

RDB SCADA
RDB CM
RDB CMMS
RDB

Mapping and Semantic Querying

Production Ontology

Maintenance Ontology

Prognosis Ontology

Data as a Service

Data as a Service

Analysis as a Service

Data as a Service

On-line data streams

Sensing

RDB
RDB
RDB
RDB
Context-Aware PdM

- Measurements related to selected unit
- Maintenance actions related to selected unit HIGHLIGHTED IN RED
- Available measurements/features

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Findings:

- **Cloud-based prognosis**: leverages advanced manufacturing by using data and information from across manufacturing hierarchy to improve efficiency, productivity, and profitability;
- **Products and services from cloud**: benefit customers in process monitoring, diagnosis, and prognosis;
- **Cloud-based prognosis**: well aligned with **Industry 4.0** and **Smart Factories**.

Future Research Directions:

- **Standards** for data **interfaces, collection, transmissions, and interoperability** for effective and efficient data processing and sharing;
- **Guidelines** for sensors and prognostic models **selection** and cooperative **decision-making**, to ensure robust and reliable prognosis;
- **Challenges** on dynamic computing/manufacturing resource allocation, network **bottlenecks, cybersecurity, and data security**.
Other Remaining Challenges

- **Complexity**: Systems of Cyber-Physical Systems
- **Connectivity**: Internet of Things
- **Information Explosion**: Big Data Management
- **Volume**
- **Velocity**
- **Variety**
- **Security**
- **Safety**
- **Privacy**
4V of Big Data

The FOUR V’s of Big Data

Volume

- 40 Zettabytes (40 trillion gigabytes) of data will be created by 2020, an increase of 300 times from 2005
- 6 billion people have cell phones

Variety

- 30 billion pieces of content are shared on Facebook every month
- 400 million tweets are sent per day by about 200 million monthly active users
- 4 billion+ hours of video are watched on YouTube each month

Velocity

- The New York Stock Exchange captures 1 TB of trade information during each trading session
- Modern cars have close to 100 sensors that monitor items such as fuel level and tire pressure
- By 2015, 4.4 million IT jobs will be created globally to support big data, with 1.9 million in the United States

Veracity

- By 2014, it’s anticipated there will be 420 million wearable, wireless health monitors
- As of 2011, the global size of data in healthcare was estimated to be 150 exabytes (1.5 million gigabytes)
- By 2011, 1 in 3 business leaders don’t trust the information they use to make decisions
- Poor data quality costs the US economy about $3.1 trillion a year

Sources:
- McKinsey Global Institute, Twitter, Cisco, Gartner, EMC, SAS, IBM, MECTEC, GAS