Wireless Communications for Future Manufacturing Field
~Flexible Factory Project~

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Today’s Talk

• Wireless Communications and Manufacturing

• In the manufacturing field
  • Problems of wireless communications
  • Needs of wireless communications

• Toward Flexible Factory
Potential economic impact by IoT @2025

Information Gathering for Solution of Problems

- Workforce and skilled workers shortage, High-mix low-volume production,
  Change of value chain

- US$ 1.2 trillion (Low estimate)
  e.g.) Public safety and health, Traffic control, Resource management

- US$ 3.7 trillion (High estimate)
  e.g.) Operations Management, Predictive Maintenance

- Factories
- Cities
- Human
- Retail
- Outside
- Work sites
- Vehicles
- Homes
- Offices

Source: McKinsey Global Institute Report
Reconfiguration of production line

- Inspection process in the production line

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

  3 times /year

Change sequence of systems

The assembling tool has a role of inspection machine

Future usage of wireless communications

Current usage of wireless communications

Smart Resource Flow
Why not wired?

Disconnected! ?

Messy!!!!

Information has to deliver right place.
Communication Nodes for Factory Automation

Share of wireless nodes is 4%, but is increasing at an annual growth rate of 30%.

Fieldbus 58%  
Annual growth 7%

Wireless 4%  
Annual growth 30%

Industrial Internet 38%  
Annual growth 20%

HMS’s estimation for 2016 based on number of new installed nodes in 2015 within Factory Automation.

Independent Wireless Systems

Step-by-step installation for each equipment or process flow resulting in complexity with independent wireless systems.

- Standard-compliant wireless systems using ISM or globally available frequency-bands.
- Non-standard wireless systems.
- Small-power specified wireless systems.

### Industry specific and applicable wireless standards

<table>
<thead>
<tr>
<th>Frequency Band</th>
<th>Industry specific</th>
<th>Industry applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>920MHz</td>
<td></td>
<td>Wi-SUN SIGFOX LoRa Wi-Fi/HaLow</td>
</tr>
<tr>
<td>2.4GHz</td>
<td>WirelessHART ISA100.11a WSAN</td>
<td>Wi-Fi Bluetooth, BLE Zigbee</td>
</tr>
<tr>
<td>5GHz</td>
<td></td>
<td>Wi-Fi</td>
</tr>
<tr>
<td>60GHz</td>
<td></td>
<td>Wi-Fi/WiGig</td>
</tr>
</tbody>
</table>
What is most important thing?

• Top priority issues in the manufacturing field are…
  • Productivity
  • Quality
  • Security

Of course, they are most important for introduction of Wireless Communications!
Flexible Factory Project

Efforts to solve real problems in the manufacturing fields.

- Revealing crucial requirements for wireless communications.
- Conducting wireless environment evaluation and wireless packet transmission tests at factories in operation.

Collaborating work since 2015

- Participants:
  - NICT
  - OMRON
  - ATR
  - NEC
  - NEC Communication Systems
  - FUJITSU
  - FUJITSU KANSAI-CHUBU NET-TECH
  - Mobile Techno
  - Sanritz Automation
  - MURATA MACHINERY

- Partners: 7 factories of 5 companies
Challenges for Wireless Utilization in Factories

**Dynamic Wireless Environment Change**
- Motions of materials, parts, products, and carriers in a closed space.
- Retooling, equipment changeover, and system on/off.
- Layout reconfiguration, and production-line installation.

**Diverse Wireless Environment**
- Depending on scale of the facilities, existence of obstacles for radio propagation, noises, and the number of deployed wireless systems.

**Independent Wireless Systems**
- Step-by-step installation for each equipment or process flow.
- Coexistence of heterogeneous and legacy devices/systems.

Flexibility is a key to address the issues.
# Delay Tolerance

<table>
<thead>
<tr>
<th>Delay Tolerance</th>
<th>1msec</th>
<th>10msec</th>
<th>100msec</th>
<th>1sec</th>
<th>10sec</th>
<th>100sec</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td>Machine, Robot</td>
<td>AGV with rails, Rotary equipment</td>
<td>AGV w/o rails</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Quality</strong></td>
<td>Inline inspection</td>
<td>Machine operation/production recording</td>
<td>Line monitoring</td>
<td>Logging</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Management</strong></td>
<td>Preventive maintenance for tools, Machine monitoring</td>
<td>Positioning, Motion analysis, Inventory control</td>
<td>Facility environment control</td>
<td>Preventive maintenance for machines</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Display</strong></td>
<td>Work instruction</td>
<td>Andon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>Emergency warning</td>
<td>Dangerous behavior detection</td>
<td>Vital sign monitoring</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Flexible Factory Project
## Diverse Wireless Environment

### List of Evaluated Factories in Operation

<table>
<thead>
<tr>
<th>Factory #</th>
<th>Process</th>
<th>Scale</th>
<th>Residential Areas</th>
<th>Shielding Objects</th>
<th>Noise from Machines</th>
<th>Unwire Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Printed circuit board assembly</td>
<td>Small</td>
<td>Near</td>
<td>No</td>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Large-machine assembly</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Large-machine assembly</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Large-machine assembly (same as #2, measured half year later)</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Printed circuit board assembly</td>
<td>Medium</td>
<td>Isolated</td>
<td>No</td>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Large-metal mold casting</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>Yes</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Large-metal</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Large-metal processing (same as #7)</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Large-metal processing (same as #7)</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Large-machine assembly (same as #2, measured 1.5 year later)</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>11</td>
<td>Large-metal press</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>Yes</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Large-metal welding</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>Yes</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Printed circuit board assembly</td>
<td>Large</td>
<td>Isolated</td>
<td>No</td>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>Steel works</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
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<tr>
<td>15</td>
<td>Food Manufacturing</td>
<td>Large</td>
<td>Isolated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Medium-size metal parts assembly</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Medium/large-metal forging</td>
<td>Large</td>
<td>Isolated</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

1. Location
2. Scale of the facility
3. Obstacles for radio propagation
4. Machine noise in microwave frequency
5. Evolutonal stage for wireless utilization
Long burst-loss observed at higher data rates.

- Significant loss measured at 54Mbps for 2.4/5GHz (IEEE802.11g).
- Maximum burst-loss duration: 1sec for LOS, 4sec for NLOS.

### Burst Loss in the Factory

<table>
<thead>
<tr>
<th>Data Rate (Mbps)</th>
<th>Maximum Burst-loss Length (LOS)</th>
<th>Maximum Burst-loss Length (NLOS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>20</td>
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<tr>
<td>30</td>
<td>30</td>
<td>30</td>
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<tr>
<td>40</td>
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<td>40</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>
Effect of metal for wireless communications

Comparison of packet loss (NLOS)

- with large machines surrounded
- w/o large machines surrounded

Packet Loss (%) vs. Data Rate

- 54Mbps
- 48Mbps
- 36Mbps
- 24Mbps
- 12Mbps
- 6Mbps

S: Slave
M: Master

Large Metal Cutting Machine

Wall

4m

27.5m
Noises in Factories

**External and internal noises at 2.4GHz**
- Wi-Fi access points placed in residential area near the factory.
- Inverters of motors in equipment in the factory.

Factory for printed circuit board assembly near residential area

Factory for large-metal mold casting
Mix Heterogeneous Systems

• Sequence of introduction of wireless communications
  • Switch, remote controller, RF-ID tag etc. (not control)
  • Use 2.4 GHz band

![Graph of wireless communication signal strength over time]

- Factory of Large Metal Process (2016/02)
  • Past: Automatic Guided Vehicle (AGV) using 5GHz wi-fi (about interference of other systems of 2.4GHz)
  • Now: ICT infrastructure also use 5GHz wi-fi → Battle
Dynamic Change of Wireless Environment

920MHz

(1) 2015, July

(2) 2015, Dec.
City Infrastructure Glow

Growth of City (Traditional Style)

Health, Safety, Security

ICT Competitiveness index

- Mexico city
- Beijing
- Jahanessburg
- Singapore
- Paris
- New York City
- Stockholm
- London
- Munbai
- Sao paulo
- Sydney
- Tokyo

Direct Introduction of wireless technology (Recently Style)

PricewaterhouseCoopers, 2013
Unwire Stage

Data Size is smaller than 50 Byte not sensitive about data delivery delay

Inter-company backbone system and IP phone, monitoring data using wireless communications

several systems (sensing systems and RF-ID etc.)
Example of Mature Stage 1
Communication Quality Specific Optimization Stage

Packet delivery delay of channel using Automatic Guided Vehicle (AGV) control

Tact: One unit time of manufacturing line

Long CSMA/CA waiting time: Sending huge number of same data packets

Typical packet delivery delay

Bandwidth are free but high possibility of communication problems
**Evolution of manufacturing tools**

**Now**

**Small-Volume Data**
- Wireless Poka-yoke
- Screw Tightening OK
- 20~30Byte*O(1)/O(10)sec
- O(100)sets/line

**Future**

**Large-Volume Data**
- Wireless Poka-yoke
  - Screw Tightening OK + torque waveform
  - (20~30Byte + 20~30Kbyte)*O(1)/O(10)sec
  - O(100)sets/line

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**Next Generation Wireless Poka-yoke**

- OK
- No gap
- NG
- Gap

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**Graph**

- X-axis: 時間 (s)
- Y-axis: トルク (N·m)
- Data points showing expected OK and NG outcomes.
When we will change parts of machine?

This spark is OK, not need to change it now.

We have to keep quality of products. Now we should change this part!

Spark! Should I change parts now?

We could use it more longer!

Not-skilled worker

Skilled worker

The key issue is how to sense the sense of skilled works.
Example of Mature Stage 2
Application Specific Optimization Stage

- Long term, high frequency, huge data
  ex) Video Stream, waveform data etc..

- Few applications occupy a bandwidth

- Breakdown Maintenance
- Inspection Maintenance
- Time Based Maintenance
- Condition Based Maintenance
- Corrective Maintenance
- Preventive Maintenance

Few applications occupy bandwidth
Wireless Communication with AI

- Definition of the communication requirement for Condition Based Maintenance
- Dynamic Communication Management with AI

Real-time Visualization of Wireless Communications
Collaboration with DFKI
Toward Flexible Factory

• Wireless communications receive a lot of attentions

• Special problems of wireless communications in the manufacturing field
  • Dynamic wireless environment change
  • Diverse wireless environment
  • Independent wireless systems

• Make clear
  • Purpose of application

• Utilizing limited and fluctuating radio resources
  • Harmonized over different wireless systems
  • Application-aware coexistence
Special Thanks

- OMRON Corp.
- Advanced Telecommunications Research Institute International
- NEC Corporation
- NEC Communication System Ltd.
- FUJITSU LIMITED
- FUJITSU KANSAI- CHUBU NET-TECH LIMITED
- Mobile Techno Corp.
- Sanritz Automation Co., Ltd.,
- MURATA MACHINERY LTD
- Many factories support our research activity and field experiments.