Intelligent Manufacturing in the Past, Present and Future

Leo van Moergestel
HU Utrecht University of Applied Sciences
Utrecht University
Utrecht, the Netherlands
Let me introduce myself

- Utrecht University of Applied sciences
  - Research team Micro Systems Technology (prof. Erik Puik)
- Utrecht University
  - Member of the Intelligent Systems group (prof. John-Jules Meyer)
Some of my books
Translations to Dutch
Overview

- Part 1: Manufacturing overview from past to current state
- Part 2: My research (is this the future?):
  - Agent-based manufacturing
  - Agent-based product support
Overview Part 1

• Industrial revolutions
• Standard manufacturing
• Modern technologies
• Concepts and hot topics
• Point of concern
Intelligence in manufacturing
Mass production
In time more advanced machinery
Industrial revolutions

- Power driven systems (steam, waterpower)
- Electrical driven systems, production lines
- Automation with electronics and IT
- Cyber connected systems
Revolution 1

- Introduction of mechanical production facilities with the help of water and steam power
- The first power loom was designed in 1784 by Edmund Cartwright and first built in 1785.
Revolution 2

- Division of labor, mass production, production lines
- Use of electric power
- First assembly line Cincinnati slaughter houses (1870)
- Remember 'Modern Times' (Chaplin)
Assembly line
Revolution 3

- Automation by electronics, IT and advanced electro-mechanical systems like industrial robots
- First Programmable Logic Controller (PLC) Modicon 084
Revolution 4

- Cyber-physical systems
- Smart interconnected systems communicating, sharing information, negotiating and making decisions
How things are made

- Single product (unique, tailor made)
- Continuous production (chemical industry)
- Batch production (food, consumer products, industrial products)

- Both continuous and batch are considered industrial production
Example: single product
Example: continuous production
Example: batch production
Batch results
Control layers

Business Systems - Intranet Networks

Quality, validation → Maintenance → MES → Scheduling → Management Information

Public

Supervisory Network

Operator Consoles → SCADA → Batch Control → Lab Info Syst.

Control System Network

Storage Management

PLC's → Control Stations → Fieldbus → Field

Safety System

Smoke, Gas & Fire detection

Field Instruments
Intermezzo PLC

- Programmable Logic Controller
  - LD (graphical, relay logic)
  - IL (Textual, low level commands like assembler)
  - ST (Textual, Pascal-like procedural language)
  - FBD (graphical, logic diagrams)
  - SFC (graphical, state machine, GRAFCET)
Intermezzo PLC
PLC programming 2(2)
Intermezzo Fieldbus

valve

Fieldbus

Control System

Level sensor

hla

lla
Producer-consumer network
Profibus

Token passing

PC

PLC

PLC

Masters

Profibus

Profibus

Slaves

M

I

M

T
SCADA

• Supervisory Control And Data Acquisition
• Operates at a lower level than the Manufacturing Execution System (MES)
• Several commercial solution providers
• Connection with production system generated data
• Control at operator level.
MES (11 tasks)

- Resource allocation
- Operations scheduling
- Dispatching production units
- Document control
- Data collection
- Quality management
- Labor management
- Process management
- Maintenance management
- Product tracking
- Performance analysis
Concepts and hot topics

- What are concepts and hot topics in modern manufacturing?
  - Lean manufacturing
  - Agile manufacturing
  - RMS
  - Personalizing products
  - Short time to market
Lean Manufacturing

- TPS
- What is the product value for the consumer?
- Discover where this value is added during production
- Determine waste in the process, remove it and shorten the duration of lead time
- Apply pull-driven production
- Keep the waste away
Agile Manufacturing and RMS

- **Definition:** An agile manufacturing system is a system that is capable of operating profitably in a competitive environment of continually and unpredictably changing customer requirements.

- **Definition:** A reconfigurable manufacturing system is a manufacturing system that is designed for fast changes, both in hardware as well as software components, in order to quickly adjust production capacity and functionality in response to sudden changes in market or in changes in requirements.
Personalizing 1(3)
Personalizing 2(3)
Personalizing 3(3)
Time-to-market

New Product → Upscaling to Real Production Equipment → Test Batch → Production Batch

Research and Development (R&D) → Production Floor

Adjust Parameters

Time to Market
Security is a point of concern
Conclusion so far

- Standard manufacturing automation is mostly based on industrial production (batch processing and continuous processing).
- This kind of manufacturing will not disappear but other solutions might be useful.
- Why is there a need for other solutions?
  - Customers want personalized products
  - New technologies available
  - Short time-to-market needed
Overview of part 2

• Industry 4.0
• Agent-based manufacturing
• Production grid
• Product flow in the grid
• Grid adaption
• Results
Industry 4.0

The 4th Industrial Revolution - "Industry 4.0"

- **Drivers**
  - Quality of life
  - Engineering Sciences
- **Mobility**
- **μ-electronics**
- **ICT**

**1st**
- steam engine
- **1782**
- Power generation
- Mechanical automation

**2nd**
- conveyor belt
- **1913**
- Industrialization

**3rd**
- Computer, NC, PLC
- **1954**
- Electronic Automation

**4th**
- Cyber Physical Systems
- **2015 Smart Automation**

smartFactory®

© smartfactory-KL 2013-8
Industry 4.0

EXHIBIT 2 | Industry 4.0 Is Changing Traditional Manufacturing Relationships

From isolated, optimized cells...

TODAY

...to fully integrated data and product flows across borders

Greater automation will displace some of the least-skilled labor but will require higher-skilled labor for monitoring and managing the factory of the future

Integrated communication along the entire value chain reduces work-in-progress inventory

Machine-to-machine and machine-to-human interaction enables customization and small batches

Source: BCG.
Initiatives everywhere
Manufacturing Challenges Resumed

- Short time to market
- Customer specific products
- Small quantities

Possible solution: Grid production

- Based on a grid of versatile production platforms (called equiplets)
- Agile and scalable software infrastructure
Enabling technologies

- 3D printing (additive manufacturing)
- Fast and reliable (wireless) networking
- Cheap powerful single board computers
- Cheap robotics
Classic pipeline production

Fixed product path
Similar products
Huge batch size
Grid production 1(2)

Different product paths (product threads)
Different products (multi parallel production)
Small batches or single product manufacturing
Grid production 2(2)
Example of a product path

```
production steps
1 -> 2 -> 3 -> 4

5 -> 6 -> 7

product thread
8
9 -> 10 -> 11

equiplet A
equiplet B
equiplet A
equiplet C
```
Product agent and equiplet agents

- equiplet A
  - equiplet agent
  - equiplet agent frontend A

- equiplet B
  - equiplet agent frontend B
  - product flow

- equiplet A
  - equiplet agent frontend A

- equiplet C
  - equiplet agent frontend C

- product agent path
  - product flow
Grid production

- equiplet A
- equiplet B
- equiplet C

- switch
- central system
- production grid monitor
Equiplets with different frontends
ICT infrastructure solution

• Every product is (possibly) unique
• Every product has its production steps
• Distributed system

• A product agent represents the product and knows what (production steps) to do
• An Equiplet agent represents the equiplet and knows how to do (certain production steps)
Agents

- Autonomous systems
- “Living” in an environment
- Sensing, acting, reacting

Definition by Wooldridge and Jennings:

“An agent is a computer system that is situated in some environment and that is capable of autonomous action in this environment in order to meet its design objectives”
Agent design objective or goal

Mission: Go to Gap, Buy a Pair of Pants

- Male
  - Time: 6 min
  - Cost: $33

- Female
  - Time: 3 Hrs 26 min
  - Cost: $876
MultiAgents

- Interacting agents
- Roles, communication
- Cooperation, negotiating
Multiagent production 1(2)

Equiplet agents publish their production steps on a blackboard.

Product agents choose the equiplets and make reservations for these equiplets.

Product agents negotiate to find a solution in case of scheduling problems.

Product agents collect production information to build a product log.
Multiagent production 2(2)

Equiplet agents have a frontend (thus a set of production steps)

Equiplet agents publish these production steps on a blackboard

Equiplet agents wait for product agents to arrive

Equiplet agents send production information to product agents when performing a production step
Problems to be solved

Path planning
Production scheduling
Product logging
Transport (materials and products)
Error recovery
Software architecture
Architecture

MAS

Product Agent

Planning Blackboard

Production Steps Blackboard

Equipt Agent

ROS

Database

Equipt Node

Pick & Place Node

Vision Node

LINUX

Gripper

Motors

Camera
Implementation

- Webbrowser
  - HTML5
  - Javascript
- Webserver
  - Tomcat
- Timeserver
  - Time process
  - BB-planning
  - BB-steps
  - BB-logfile
- Java application
  - Jade Product Agent
  - Jade Equiplet Agents
- Equiplet 1
- Equiplet 2
- Equiplet 3
  ...
Web interface

LEO
is
GEKE
Result

4EO
...
!5
Using this model in a hybrid environment

• **What to do** versus **how to do**

• This model can also be used in the situation of human workers instead of equiplets.

• A product agent *represents the product* and knows **what** (production steps) to do

• A worker agent *represents the human worker* and knows **how** to do (certain production steps)
Hybrid architecture

MAS

Planning Blackboard

Product Agent

Worker Agent

Production Steps Blackboard

Production Floor

Worker Agent-Human Interface
Implementation
Conclusion so far

The concept has been implemented in an experimental setup.

Agent technology fits well to a distributed infrastructure.

Concept can be the basis of product agents in the life cycle of a product.

The product agent is a good candidate to represent the product in the Internet of Things.
Agent-based Product Support
Life cycle of a product

- Design
- Manufacturing
- Distribution
- Usage
- Recycling

Note: the product life cycle is a different concept
What to do with the product agent when the manufacturing is done?

- Embed the agent with its information in the product
- Or transfer the information to another embedded agent
- Keep the product agent alive in cyberspace
Benefits of embedded agents

• Depends on the phase in the life cycle
• All information about a specific product is available
• Basis for implementing the Internet of Things
Embedding a product agent

a) product agent

b) Beliefs
   product agent
Risk of trusting embedded software
Conclusion

Agents can play an important role in all parts of the life cycle of a product.

A product agent is a good basis for the Internet of Things (IoT).

An aspect of IoT can be recycling and repair support.

A product agent acts like a guardian angel (except for the spiritual aspects).
Thank you!
Questions?