Fog Computing for Robotics and Industrial Automation

**Paul Pop**, Professor of Cyber-Physical Systems
DTU Compute, Technical University of Denmark

- **Ph.D. in Computer Systems**
  Linköping University, Sweden

- **Assistant professor**
  Linköping University, Sweden

- **Associate professor**
  DTU Compute, Technical University of Denmark (DTU)

- **Professor**
  DTU Compute, Technical University of Denmark (DTU)

- **Director**
  Research Center on Internet of Things at Technical University of Denmark
**Industry 4.0**

**Definition** Digitization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyberphysical systems, and analysis of all relevant data.

**Benefits**

- **Indicative quantification of value drivers**
  - 10 - 40% reduction of maintenance costs
  - 20 - 50% reduction in time to market
  - Forecasting accuracy increased to 85+%3
  - Costs for quality reduced by 10 - 20%5
  - Costs for inventory holding decreased by 20 - 50%3
  - Productivity increase by 3 - 5%5
  - Asset utilization
  - Time to market
  - Supply/demand match
  - Quality
  - Inventories
  - Labor

**$15 Trillion**

Increase in global GDP with **Industrial internet** over the next 20 years

Source: McKinsey
“Software is eating the world”

IT has transformed our society.
Everything is now software in the Cloud.

What do all of these have in common?

Will the factory move to the Cloud?
The automation pyramid and OT

Operations technology (OT) - The hardware and software dedicated to detecting or causing changes in physical processes through direct monitoring and/or control of physical devices such as valves, pumps, etc.

The Automation Pyramid:
Soon to be Ancient History?

- Rigid infrastructure with separation between levels of functionality
- Levels connected by dedicated, specialist networks
- Data exchange only via gateways or proprietary systems
- Difficulties to transparently access data at the cyber pyramid (machine) level

Source: TTTech
We cannot move the factory to the Cloud because of OT

Tough High dependability, long lifetime, safety-critical requirements Hard real-time

Reboot? Retry? Restart?
What is Cloud that comes close to the ground (edge of the network)?

What is Fog Computing? System-level horizontal architecture that distributes resources and services of computing, storage, control and networking anywhere along the continuum from Cloud to Things.

Similarities: (Dependable Real-Time) Edge Computing

Source: Flavio Bonomi
Industry 4.0 = Convergence of IT and OT

Information Technologies:
- Virtualization, Big Data, Automation
- Analytics, Scalability, SDN, Security and Privacy

Operations Technologies:
- Real-time, Safety, Reliability, Control, Machine Connectivity and Data Acquisition, Human Machine Interface
Vision: OT becomes virtualized
A history of Fog

Sept 2010
Bay area

Source: Flavio Bonomi

April 2016 Hannover Messe

KUKA calls it Real-Time Edge Computing
Fog: Converged Functionality for Industrial Automation

- ERP/MRP System
- Manufacturing Execution System
- Cell Controller
- Robotics Controller And Visualization
- PLC System
- Machine Vision and Bar Code Reader

Converging Functionality

Adding Functionality

Source: Flavio Bonomi
Fog Computing: a new Infrastructure layer

1. Communications, gateway networking convergence
2. Edge data management, analytics
3. Distributed application hosting
4. Virtualization of all resources, multi-tenancy
5. Security and Privacy
6. Real-time, local control
7. Scalability
8. Reliability
Fog: Hardware convergence

3 Slot System:  
20-30 Industrial PCs

3 Slot System:  
~15-20 IoT Gateways

Real-time, High-availability,  
Industrial Fog Node  
Virtualizing and consolidating,  
multiple PLCs and Industrial PCs  
(SBCs)

Industrial Micro-controller PLC  
Industrial PC  
IoT Gateway  
Data center Servers or Micro-Servers
**Fog: Virtualization and Security**

**Virtualization** A combination of physical separation ( multicore), hard, RT-NRT Virtual Board/Machine based virtualization and more lightweight Linux Container based virtualization.

![Diagram of virtualization and security](image)

- **LXC**: Linux Container
- **GuestOS+Hypervisor (KVM)** or Thin Hypervisor (Wind River, Lynx,..)

**Security** Decentralized model, including distributed authentication, trusted booting, secure software management, SDN based connectivity control, OpenVPN, NFV Security...
Network convergence: IEEE Time-Sensitive Networking

Principles **Integration**

Multiple traffic classes share the network, supporting applications with mixed-criticality requirements

**Separation:** Virtual links separate different criticalities

### Standardization as IEEE TSN

A number of IEEE 802.1 standards due for release early in 2017

- **Synchronous (Time-Critical):**
  - SAE AS6842 clock synth.
  - IEEE 1588compensate
  - Real-time control
  - Ultra-low latency
  - Safety systems

- **Streaming (Time-Sensitive):**
  - Rate-constrained (AVB)
  - Rate-constrained (M64p7)
  - Audio/video
  - Sensor fusion

- **Ethernet (Regular Traffic):**
  - IEEE 802.3 standard traffic
  - Best effort

---

**Source:** http://www.ieee802.org/1/pages/tsn.html
Open standards will win: IEEE 802.1 TSN and OPC UA over TSN

Creating a Flexible IoT Infrastructure with Deterministic Ethernet

- OPC UA over TSN: one unified architecture for all communication infrastructure elements
- Logical machine/control boundaries are dissolved
- Direct access to machine data from ERP/MES
- Real-time and non-real-time domains integrated
- OPC UA provides leading technology of proven security concepts

Learning from the Internet Experience: Digital Platforms and Open Innovation win.

Source: TTTech
Software convergence: an app store for the factory
Safety: Certification is very expensive

For safety-critical systems, decision-makers require pre-release safety assurance evidence that it manages risk acceptably.

Highly critical systems require certification by a regulatory authority.

Source: Hans Hansson
The industry is not the new “space customer”

Components are produced for computers and consumer electronics; they have 3-6 year production lives and narrow operating temperature ranges. The needs of the “space customer” are not addressed. Industry is not prepared to pay “space customer” prices.

Source: Boeing
Security concepts such as user-based access control apply less often in OT systems than they do in IT.
The Cloud will come to the factory

High risk of change, but!

High impact, and new equipment needed only for about about 40 to 50% of installed base

Source: McKinsey
Industry 4.0 vision: Research at DTU Compute

FORA proposal: 15 PhDs
Fog Computing for Robotics and Industrial Automation
DTU’s IoT Center, iotcenter.dk

We are open to researchers from other departments at DTU, other Danish universities, and we’re welcoming company members.

Mission: Performing research on IoT technologies and facilitating collaboration among researchers and practitioners in Denmark.

Vision: Dependable and secure IoT enables efficient solutions to societal challenges.

Prof. Paul Pop. Industrial IoT
Prof. Nicola Dragoni. IoT Security and Privacy
Prof. Jens Sparsø and Assoc. Prof. Martin Schoeberl. IoT Platforms
Assoc. Prof. Michael S. Berger. IoT Communications Infrastructure
Prof. Henrik Madsen. IoT Cyber-Physical Modeling and Smart Energy IoT
Prof. Lars Kai Hansen’ group. IoT Data Analytics
Prof. Jan Madsen. Health IoT
Assoc. Prof. Sven Karlsson. IoT System Software

Research Center on Internet of Things at Technical University of Denmark
Thank you!

IT-OT gap crossed with multi-disciplinary, inter-sectoral, international Research