Simulation and Design of Networked Embedded Systems

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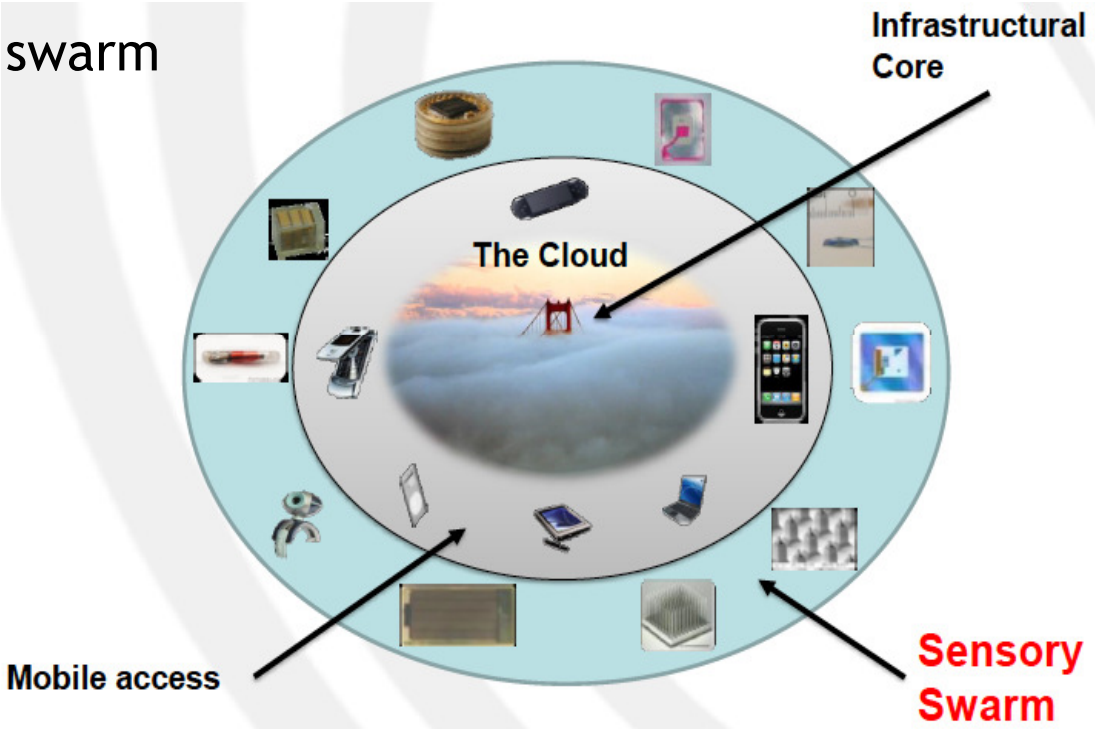
Outline

- The emerging IT scene
- Definition of networked embedded system
- Modeling and simulation of networked embedded systems
- Network synthesis
- Design of Networked Control Systems
- Verification of network software
- Applications

The Emerging IT Scene

- A continuous of:
  - smart devices: the sensory swarm
  - interconnection
  - computational resources



- Open issues:
  - Modeling
  - Design
  - Validation
  - Interfaces generation
- Possible answer:
  - Moving design techniques from the single embedded system to the swarm

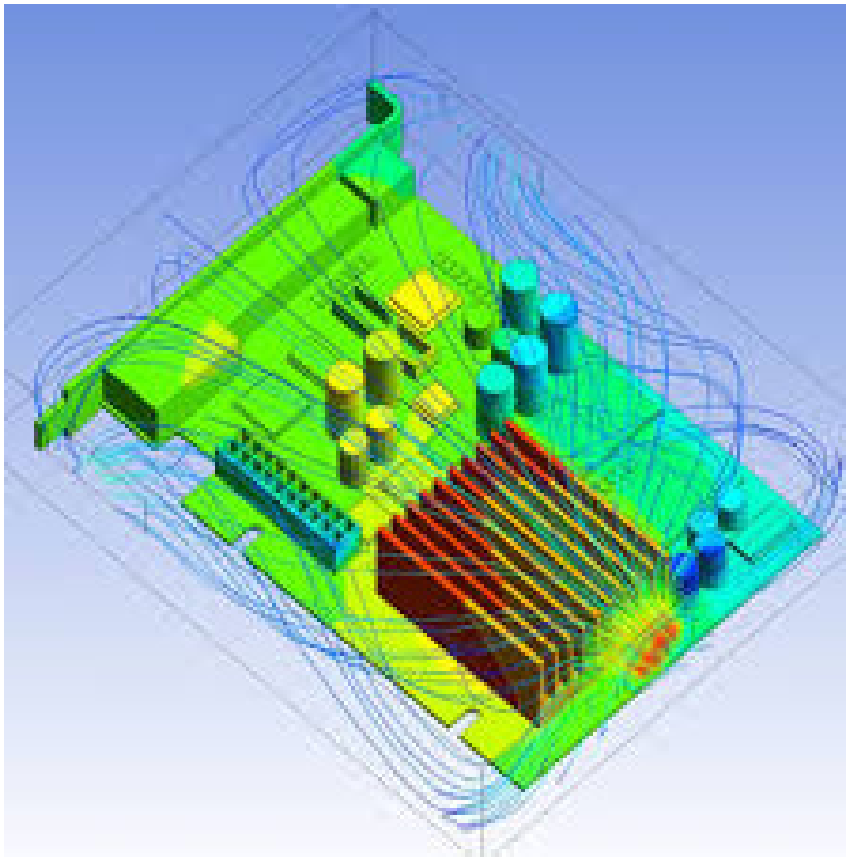
Networked Embedded Systems

- Networked embedded systems (NES) are small, intelligent, embedded systems able to communicate each other and with Internet
- Key terms
  - Internet of Things
  - Machine-to-machine
  - Smart systems

Modeling & Simulation of NES

Objectives

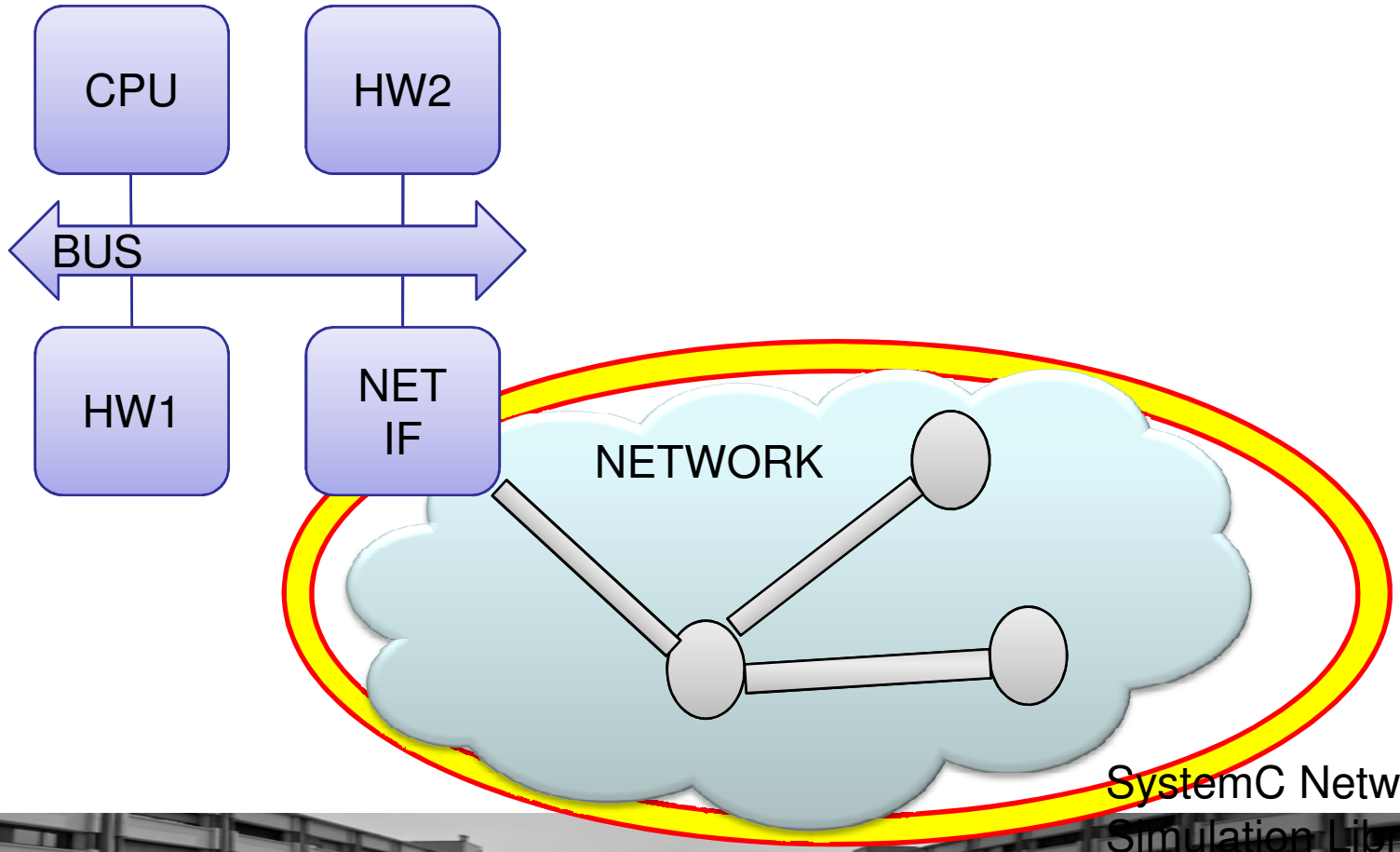
- This research topic regards the creation of **models** and **simulation** of
  - Digital hardware
  - Software
  - Network activity
  - Network channel
- Languages
  - UML
  - SystemC



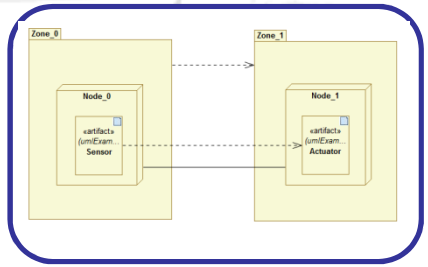
SystemC Network Simulation Library

- Extension of SystemC to simulate packet-based networks
- Provides modeling primitives for:
  - Packet transmission/reception
  - Channel contention
  - Wireless path loss
  - Antenna modeling
- Networked virtual platform
  - The network scenario is seen as a SystemC component of the virtual platform
  - Compatible with all commercial virtual platform solutions

Networked virtual platforms



UML network modeling



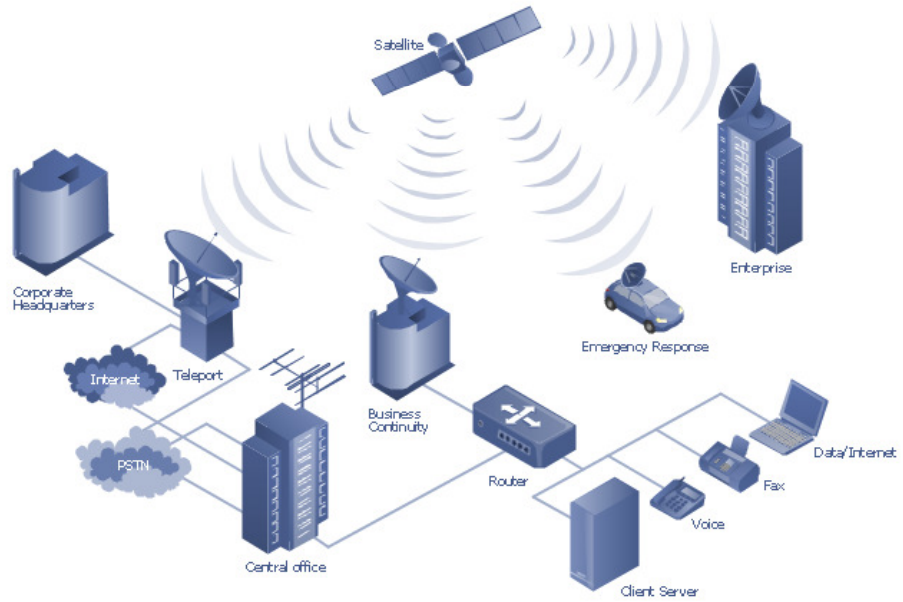
UML/MARTE

SystemC Network Simulation Library

Network synthesis

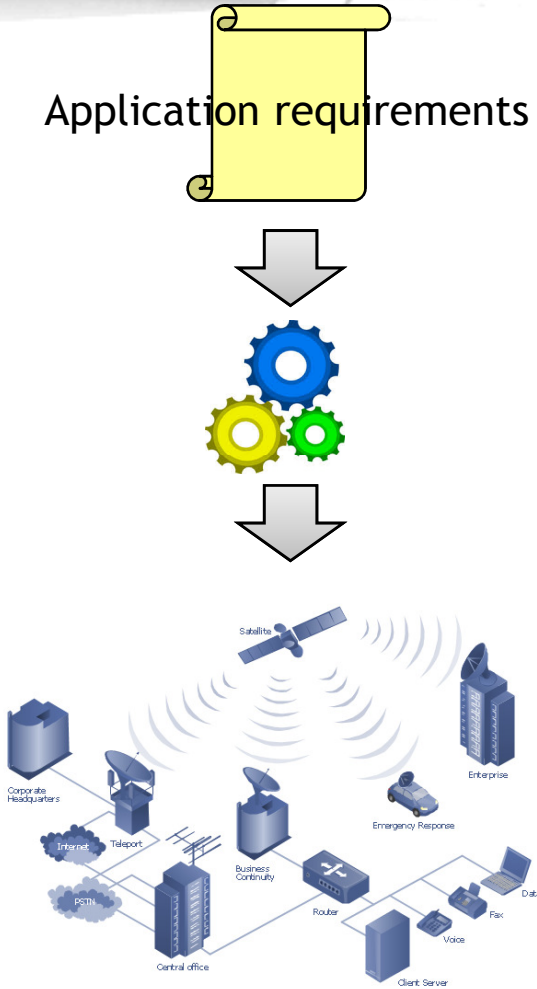
Motivation

- Challenging size and heterogeneity of today's and future's networks
- How many
  - wireless protocols?
  - Channel types?
  - Protocol parameters?



Network synthesis

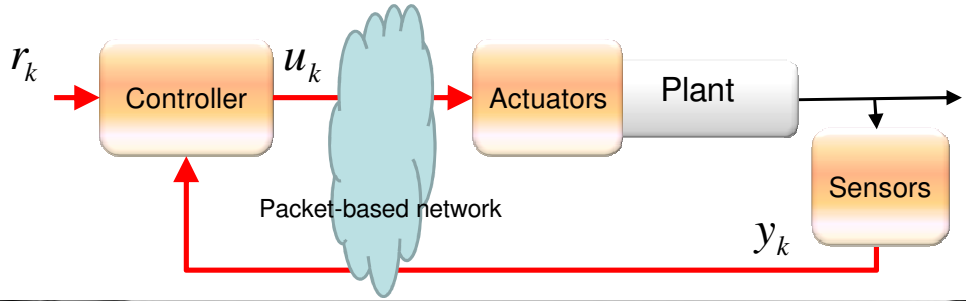
- Automatic methodology to design the network infrastructure
  - Topology
  - Nodes (number, type)
  - Channel types
  - Protocols
- Optimal allocation of resources with respect to given metrics (e.g., cost, bandwidth, delay, robustness)



Design of Networked Control Systems

Context

- Physical systems controlled through a packet-based network
  - Higher scalability
  - Re-use
  - Cost reduction
- Applications
  - Smart manufactoring
  - Automotive
  - Aerospace



Problem statement

- Packet-based networks introduce new issues for the control application
  - Latency (constant and time-varying)
  - Packet losses
  - Security vulnerabilities
- Traditional approaches
  - Robust controllers (but less control performance)
  - Secure communication protocols (more resource consumption)

Proposed approaches

- Joint design of controller and network
  - Protocols
  - Quality of service mechanisms
- Physical-based security mechanisms
  - Detection of malicious actions from corrupted signals by using a physical perspective

Verification of network software

Motivation

- Today many network aspects are implemented as software
  - Protocols
  - Software-defined radio
  - Software-defined network
  - Network function virtualization
- Networks are entered application domains which require safety certifications
  - Automotive
  - Aerospace

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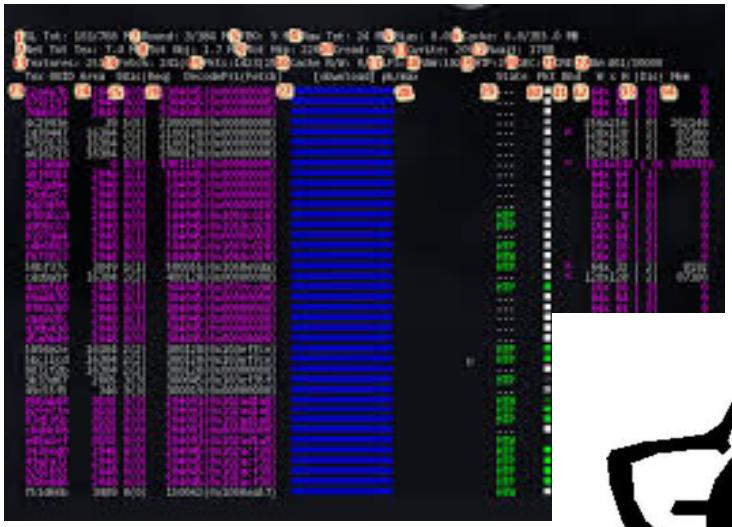
Problem

- How to find bugs in network-related SW more efficiently?
- We have observation of network activity
  - Simulation traces (e.g., through the previously described networked virtual platforms)
  - Actual behavior in a real field trial



Proposed solutions

- Generation of run-time checkers from abstract requirements of the initial specification
- Mining of properties from observed traces and comparison with initial specification

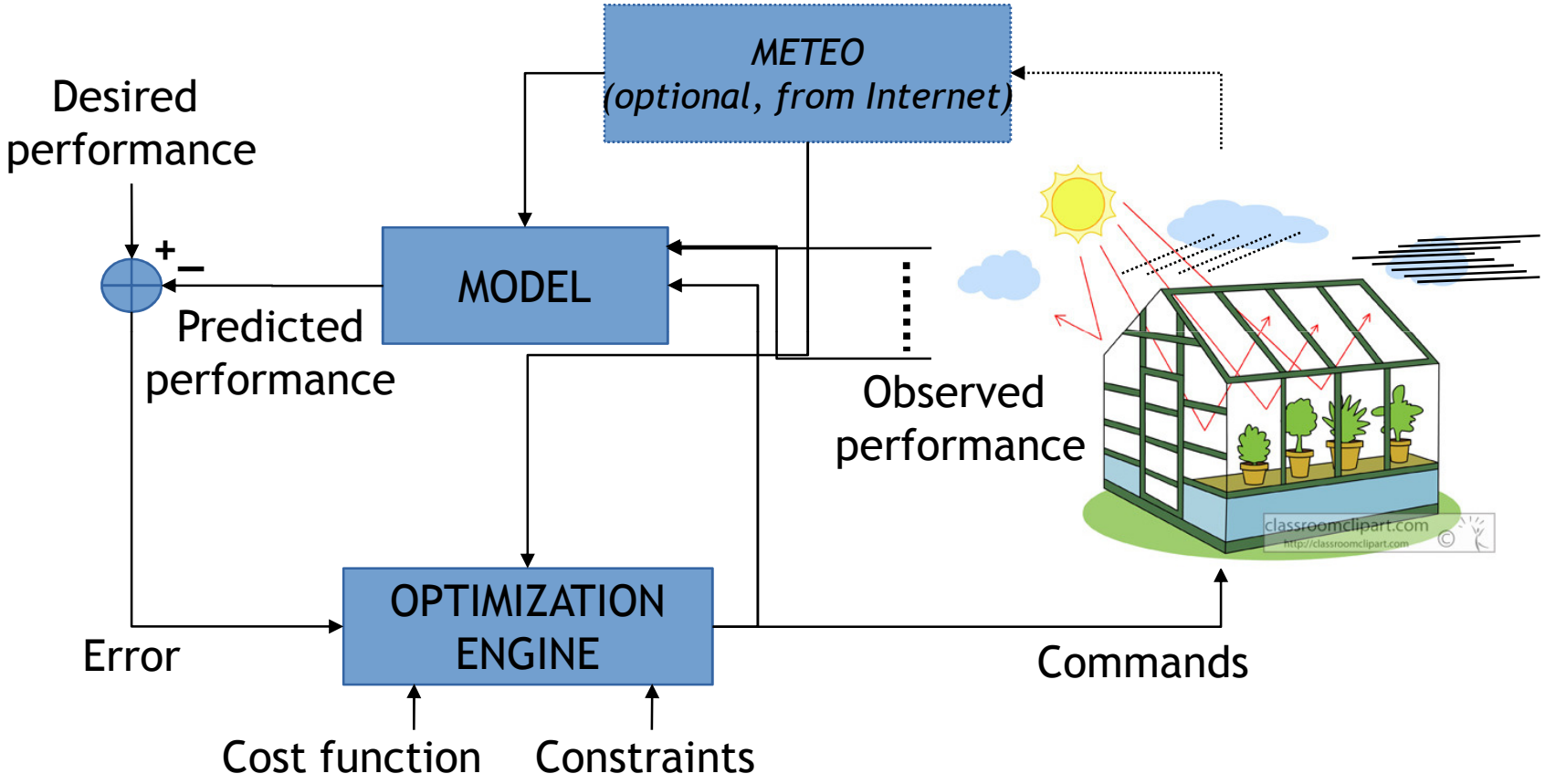
- This research has been inspired by Pravadelli's work on embedded HW and SW verification
  - Extension to network observations is challenging

Applications

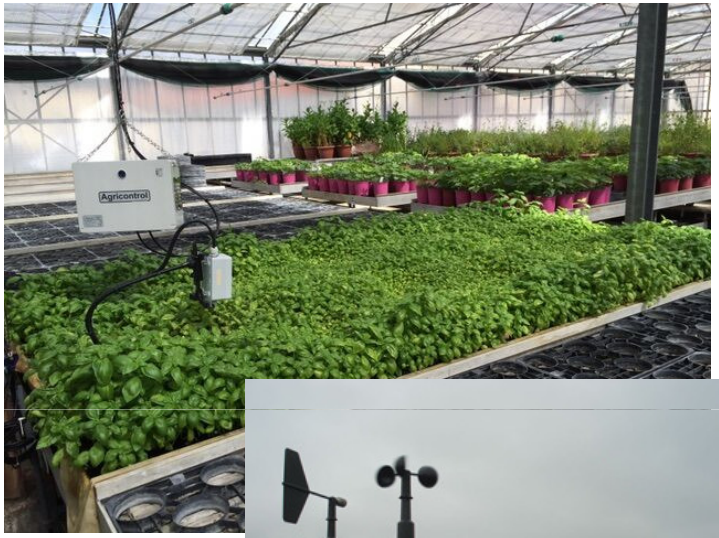
Application to smart agriculture

- EXtra-field Plant Observation for monitoring and forecast of AGRicultural Infections (EXPO-AGRI)
- Partners: Agricontrol snc, Camera di Commercio Savona
- Context: greenhouse agriculture
- Duration: 2 years
- Use of a set of networked embedded systems
  - NOT JUST for monitoring data as usual
  - BUT ALSO TO CONTROL a greenhouse
    - Disease diffusion
    - Crop timing
- Results
  - New sensors
  - Closed-loop control approach based on artificial intelligence concepts

EXPO-AGRI: objective



EXPO-AGRI: modeling



Environmental parameters:

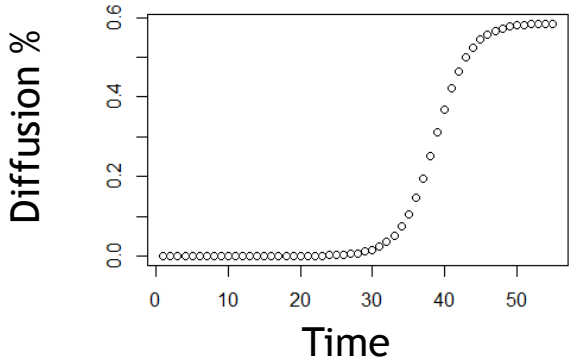
- Air temperature
- Air humidity
- Light
- …

Plant parameters:

- Leaf temperature

EFFECT

Diffusion of disease



EXPO-AGRI: new sensors

- The efficacy of the automatic control also depends on the creation of new sensors that catch better cause-effect relationships.
- Infrared thermometer
- Contactless measurement of temperature

Recent publications

- R. Muradore, D. Quaglia, Communication-Aware Bandwidth-Optimized Predictive Control of Motor Drives in Electric Vehicles, IEEE Transactions on Industrial Electronics, vol. 63, n. 9, September 2016, pp. 5602-5611.
- Riccardo Muradore, Davide Quaglia, Energy-Efficient Intrusion Detection and Mitigation for Networked Control Systems Security, IEEE Transactions on Industrial Informatics, vol. 11, n. 3, June 2015, pp. 830-840, DOI 10.1109/TII.2015.2425142.
- Emad Ebeid, Franco Fummi, and Davide Quaglia, Model-Driven Design of Network Aspects of Distributed Embedded Systems, IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, vol. 34, n. 4, April 2015, pp. 603-614.
- Parinaz Sayyah, Mihai T. Lazarescu, Sara Bocchio, Emad Ebeid, Gianluca Palermo, Davide Quaglia, Alberto Rosti, Luciano Lavagno, Virtual Platform-based Design Space Exploration of Power-Efficient Distributed Embedded Applications, ACM Transactions on Embedded Computing Systems, vol. 14, n. 3, April 2015, pp. 49:1-49:25, DOI 10.1145/2723161.
- R. Muradore, L. Repele, D. Quaglia, P. Fiorini, Improving Performance of Networked Control Systems by using Adaptive Buffering, IEEE Transactions on Industrial Electronics, vol. 61, n. 9, September 2014, pp. 4847-4856.

Thank you!

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