Hard real time in SOA systems
Application to process control

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Results from the Socrades project
Characteristics of process automation

- Many control loops (>100)
- 90 % or more are under PI control
- Model based tuning not yet standard
- Increasing amount of sensors
- Automation is an increasing part of a green field investment, and wiring may be a significant part of this
- Equipment are in well defined locations – not ”Ad hoc” networks
The General Architecture

Enterprise systems

Orchestr. i

Orchestr. j

Engineering System

Service Mediator/ Gateway

Device

Distr. IO

Controller

Work-pieces

Sensor / Actuator Network

Legacy & Low Resource Devices

IP network (wireline or wireless)
SOA at what level?
Demo at LTU 17-18 June

Physical Process

Measurements and Actuators

Wired link - actuator

OPC-UA Client

Gateway: OPC-UA Server-Siemens

800xA OPC-UA Server-ABB

Start/Stop

RF link

Level data

Wireless Start/Stop

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Lab tests of wireless communication

- Future radio environment will interfere with wireless communication
- Lab at LTU measuring
  - Latency
  - Loss of communication

![Graph and Table]

Fig. 5 Throughput characteristics versus D/U ratio

Microwave oven disturbing a WLAN channel
Disturbance rejection with packets lost

Conclusion: Difficult to compensate packet loss by prediction. Basically, when you have no communication you have no feedback!
SOA at hard real time control today?

- SW has no understanding of time
Time in application SW

- Application SW has no idea about time!!!
- Handled by OS/RTOS today
  Batch oriented paradigm
  Periodic check on events
  Thread, semaphores, priorities, ...

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SW design

components, events, reactions, deadlines

Clever software guy

threads, semaphores, monitors, priorities

Compiler

executable code

RTOS

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Can we define a semantics that understand time?
Timber - Executable Real-Time Models

- Model
  - Real-time semantics. Reactive objects:
    - **State Protected Objects**, react to
    - **Real-Time Events**, within stated time window
  - Abstraction and re-use. Functional language:
    - **Object Oriented**, component based
    - **Pure and Strict**, no side effects, predictable behavior
    - **Higher Order Language**, allowing flexible yet safe reuse
  - Safety and robustness
    - **Automatic Memory Management**, no need for pointers
    - **Strong Type System**, avoids errors and misuse
    - **Formal methods**, for system analyses of system properties
Timber - Executable Real-Time Models

- Model to Executable Code
  Timber Models compile into Equivalent C-Code Models execute on bare metal (or emulated under OS)

Timber RTS

Robust, Minimal, Self Contained kernel, no 3rd party code
Ensures State Protection of Reactive Objects
Preserves Real-Time properties for Events
Performs Real-Time garbage collection
Stack Resource Protocol (underway)
  Schedulability analysis
  Single Stack execution
Timber

- SW language where time has a meaning!! working compiler
  http://hackage.haskell.org/trac/timber/

- tinyTimber a time api fpr C
  Embedded real-time software using tinyTimber: reactive objects in C
  Johan Eriksson, EISLAB, Systemteknik (SYS)
Conclusion

- Hard real time wireless control possible today
- SOA possible to certain system level
- Emerging tools will merge SOA to hard real time wireless control
Timber Models for *Discrete* Parts of a Mechatronic System

Motor component

- Motor-ADC Wire component

- Motor-PWM Wire component

Micro-controller component

- State Root
- State Controller
  - trig
  - control
- State Sample
  - enqueue
  - sample

Interrupts:
- Interrupt 1
- Interrupt 2

ADC component

- State Root
  - start
  - iterate
  - finished

PWM component

- State Root
  - stop
  - start(fr, duty)
  - sethigh
  - setlow

Motor-PWM Wire component

Motor-ADC Wire component
Status TODAY

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Physical Process

Measurements and Actuators

OPC-UA Client Monitor

Gateway: OPC-UA Server-Siemens

800xA OPC-UA Server-ABB

Start/Stop Status

Start/Stop RF link

Start/Stop Wired link - actuator

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Characteristics cont’d

- Most loops are relatively slow (sampling interval 1 s or slower). Exceptions are e.g. drive systems and rolling mills (sampling time 10-20 ms)

- Most processes open-loop stable. Exceptions are e.g. level control, exothermic reactors.
Benefits of Wireless Technologies

- No cable wear and tear
- No connector failure
- Harsh environments

- Reduced wiring, terminals, I/O blocks, cabinets...
- Reduced design and installation work

- No mechanical design limitations
- Mobile, moving, rotating production equipment
- Fast commissioning and reconfiguration

Reliability

System Cost

Flexibility
Control communication today -- Network Architecture
Control communication history

- Mechanical and pneumatic control communication
- 4-20 mA analog communication
- Digital electrical communication
- Digital control communication buses
- ISA S50.02 standard
- Wireless Hart standard
- Bluetooth
- ABB WISA
- 1870
- 1950’s
- ~1961
- ~1988
- 1998
- 2006
- 2007
WirelessHART Networks

- Network manager
  - One manager for each network
- Gateway
  - Connects mesh network to host application
- Field devices
  - Process connected devices
WirelessHART Network Resources

- Superframe, slots, and transactions
  - TDMA
    - Reserved slots
  - CSMA
    - Shared slots
    - Contention based access - collisions are possible
  - Specification data
    - Time slot 10 ms
    - Multiple superframes may operate in parallel
Control delays in Wireless Hart

- Wireless Hart superframe
- Controller in sync
- Controller out of sync

Diagram showing time scales and states:

- **S**: Start
- **A**: Active
- **C**: Controller
- **Dc=0** and **Dc=1 s** states
Control performance as function of T & D

\[ G(s) = \frac{K e^{-Ds}}{Ts+1} \]

\[ IAE = \int_0^\infty e(t) \, dt \]

Communication delay gives performance degradation if \( T < 2 \) and \( D < 2 \)
Performance as function of Lambda & D

\[ G(s) = \frac{K_v e^{-Ds}}{s} \]
Delay compensation in Wireless Hart

Conclusion: Delays due to synchronization limited problem for slow processes. Quite possible to compensate but clearly better to synchronize communication with controller.
Packet loss compensation in Wireless Hart
Socrades

- Service-Oriented Cross-layer infrastructure for Distributed smart Embedded devices
- Integrated EU project
  9 M€, 3 year
- Partners
  ABB, Siemens, Schneider, SAP, Boliden, ....
  LTU, KTH, IFAK, POLIMI, TUT, Lboro, ....
Control over wireless link -- WP4

- Develop the continuous manufacturing device infrastructure of SOCRADES
  - Architecture for fault-tolerant wireless control
  - Control under uncertain wireless sensor and actuator communication
  - Inclusion in the service-oriented architecture, e.g. DPWS interface
- Demonstrate feasibility of the technology
Summary

- One standard available – Wireless Hart – other in progress
- Equipment are in well defined locations – not ”Ad hoc” networks
- If battery powered requires low power consumption
- Significant impact on architecture and communication
- Control algorithm needs to be robust against short as well as longer communication outages
- Will wireless control need its own frequency band?
- Deadtime in process often longer and fluctuating more than communication jitter