AGILE
RAPIDLY-DEPLOYABLE, SELF-TUNING, SELF-RECONFIGURABLE,
NEARLY-OPTIMAL CONTROL DESIGN FOR LARGE-SCALE NONLINEAR
SYSTEMS

FP7-ICT-2009.3.5: ICT for Networked Embedded & Control
Systems
C. Control of Large-Scale Systems

http://www.agile-fp7.eu

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AGILE Objectives

- Scalable and Nearly-Optimal Control for general Large-Scale Nonlinear Systems (with emphasis on systems with intense computational requirements)
- Rapid Self-tuning, Fault-Recovery, Re-configuration for general Large-Scale Nonlinear Systems
- Interfaces for Embedding the above tools to open-architecture SCADA/DCS in an “easy-to-understand” and “easy-to-operate” manner
- Implementation and Evaluation in two Large-Scale Test Cases:
  - EPB (FIBP Building, Kassel, Germany)
  - Urban Traffic Control (Chania, Greece, the whole city’s network)
**AGILE Key Issue 1**

**Dealing with Nonlinear Large-Scale Systems**

Given

- the nominal model of the large-scale system dynamics,
- the system requirements and constraints,
- possible faults and incidents and future predictions of the exogenous factors;

Provide a scalable control design that proactively schedules the Large-Scale Control System (LSCS) actions so that its performance is as close as desired to the optimal LSCS.

**Assumption:** Perfect knowledge of system and exogenous factors
AGILE Key Issue 1

Adopted Approach

- The Convex Control Design (ConvCD) methodology
- The problem:
  \[
  \text{Minimize } (\text{AGILE} - \text{OPTIMAL})^2 \\
  \text{subject to } \text{AGILE is EFFICIENT (stable and beyond)}
  \]
- Is transformed into a convex optimization problem (Least-Squares s.t. SemiDefinite Programming constraints)
AGILE Key Issue 1

Main Achievement so far

- Render ConvCD into a fully operational tool (software module) that provides:
  - Efficient and arbitrarily close to optimal controller (i.e., solves efficiently the ConvCD optimization problem)
  - Scalable controller: PieceWise Linear (PWL) or PieceWise NonLinear (PWNL) controller
  - Extension to the case where not all of the states are measurable (output feedback control) and the case of exogenous factors (predictive control)
  - Off-line performance estimates and estimates of close-to-optimality (in a similar way as standard linear control)
- Successfully tested in various small- and medium-scale systems
AGILE Key Issue 2
Adapting to uncertainties & changes

Assuming that Key Issue 1 has been successfully addressed, to provide with a computationally efficient methodology that:

- quickly detects and identifies variations and changes in the nominal system dynamics and exogenous factors as well as
- faults and atypical system behavior and
- rapidly, safely and efficiently re-designs (or even re-configures) the LSCS to effectively achieve its mission.
AGILE Key Issue 2

Adopted Approach (original)

- Combine an Adaptive Fine-Tuning scheme (successfully implemented for the automated fine-tuning of a large variety of applications)
- with Multi Mode Adaptive Control with Mixing (MMACM)
- in a *hybrid fashion*
AGILE Key Issue 2

Main Achievement so far

- Work for this Key Issue to be completed in Y2.
- Theoretical as well as simulation experiments established the validity of the proposed approach.

However: A new approach was developed that is significantly superior than the original

As a matter of fact, the adaptive control design problem can be formulated as a ConvCD problem!

AdConvCD: adaptive convCD
AGILE Key Issue 3
Embed «easily» in existing LSCS

Operator interfaces (go “beyond SCADA”)

- Develop (software interfacing) tools for existing open-architecture SCADA/DCS that
  - will allow the operator to easily incorporate a large variety of performance objectives, requirements and constraints.

1. Can you make sure that the work, experience, effort done so far is not «thrown away»?
2. Can you incorporate objectives, requirements and constraints not possible before?
3. Can you allow the operator to «tune» the control system in an «easy-to-understand» way?
AGILE Key Issue 3

Approach:

- “Translate” objectives, requirements and constraints as understood by operators (e.g. “if-then-else” rules)
- into constraints that are in a suitable form embeddable in the optimal control framework of ConvCD (nonlinear constraints).
**AGILE Key Issue 3**

Main Achievement so far

- Identification of the requirements, objectives and constraints in a variety of large-scale control applications
- Development of a methodology for translating operator-imposed requirements, objectives and constraints into ConvCD-compatible Constraints
- Development of tools for interfacing the AGILE system with existing SCADA/DCS
The AGILE Test Cases

- Test Case 1: The Traffic Network of Chania, Greece
- Test Case 2: FIBP Building, i.e., (the building we are currently in!)
The AGILE Test Cases Challenges

- Highly Nonlinear Dynamics
- Significant System Variations
- Large system dimension:
  - Test Case 1: ~80 states, 43 control inputs
  - Test Case 2: >700 states, ~170 control inputs
- Absence of a state-space models (but quite elaborate simulation models exist)
- «Hard-to-meet» constraints/rules using existing control design methods:
  - Test Case 1: Summation of green times = Cycle Time – Lost times
  - Test Case 2: if-then-else constraints (e.g., if it rains then close windows)
  - Test Cases 1 & 2: **if-then-else rules that work very well and it is not straightforward for the control design to «invent»** (e.g., if it is sunny and the temperature less than xx and ... then open blinds)
The AGILE Test Cases
2. Urban Traffic control

Location:
Chania, Greece

Characteristics:
20 Junctions
Complex Junction Geometry
Congestion
Frequent Sensor Failures and Incidents
The AGILE Test Case Building (Kassel, Germany)
## AGILE Partners

<table>
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<tr>
<th>AGILE Participants</th>
<th>Details</th>
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| 1 Center for Research and Technology – Hellas (CERTH) | 1st Coordinator: CERTH  
- CERTH & UCY lead the ConvC and AdConvCD developments  
- PSU (from USA will help on optimization & implementations)  
- AFCON & SICE lead the interfaces’ developments  
- Test Case 1: SIE & TCD  
- Test Case 2: FIBP  
- Evaluation: FIBP  
- D&E: AFCON |
| 2 University of Cyprus (UCY) | |
| 3 The Pennsylvania State University – Penn State (PSU) | |
| 4 Afcon Software and Electronics Ltd. (AFCON) | |
| 5 Sociedad Iberica de Construcciones Electricas SE (SICE) | |
| 6 Siemens AE Electrotechnical Projects and Products (SIE) | |
| 7 Fraunhofer Institute for Building Physics (FIBP) | |
| 8 Traffic Control Department – City of Chania (TCD) | |