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

Control of Energy-Positive Buildings (the Projects PEBBLE and AGILE)

E. Kosmatopoulos, K. Aboudolas (CERTH/DUTH),
D. Rovas (TUC)
GREECE

Energy Positive Buildings (EPBs): *The Set-up*

Sensing Components	Power Generation Components
•In-building sensors (temperature, humidity, occupancy, etc) •User-interfaces for user-comfort and satisfaction •Weather sensors •Smart meters •…	•Wind •Solar •μ-Turbines •…
Automatically Controlled Components	**Manually Controlled Components (through User Interfaces)**
•HVACs •Fans •Automatic Shades and Windows/Doors •Automatically controlled Electric Lighting •…	•Shades and Windows/Doors •Electric Lighting •…

EPBs: *Producing annually more than Consumed is <u>not Enough</u>*

Efficient EPBs:

Not simply

Generate more Power than Consume,

but also

Minimize the amount of power imported from non-renewable resources, i.e. exploit RES to the maximum extent possible.

- RES should be "stored" when it exceeds demand to be used later when demand exceeds RES.
- **Highly-dynamical and challenging CONTROL PROBLEM**
- **Existing control systems for Energy Efficient Buildings (EEBs) CAN NOT DO THE WORK!**

EPBs: *The Objective*

EPB Objective:

Minimize

$$\int_{\text{day or week}} \mathbf{\Pi}(t)dt$$

subject to User-Comfort & Control-Limitations constraints

- If Consumption>RES

$$\mathbf{\Pi}(t) = \text{Consumption} - \text{RES}$$

- If Consumption<RES & RES – Consumption <u>can be exported</u>

$$\mathbf{\Pi}(t) = \text{Consumption} - \text{RES}$$

- In case Consumption<RES & RES – Consumption <u>cannot be exported</u>

$$\mathbf{\Pi}(t) = 0$$

Different (more complicated) than the "conventional" EEB Objective

Minimize

$$\int_{\text{day or week}} \text{Consumption}(t)dt$$

subject to User Comfort & Control Limitations constraints

EPBs: *The PEBBLE's Approach*

Control Design Based on Optimal Control Approach

Minimize (with respect to control actions)

$$\int_{\text{day or week}} \mathbf{\Pi}(t)dt$$

subject to User Comfort & Control Limitations constraints and ***Building Dynamics***

Building Dynamics incorporate

- building thermal models;
- weather and occupancy prediction models;
- RES-generation models.

EPBs: *The PEBBLE's Approach*

Convex Control Design (ConvCD)

- Use Hamilton-Jacobi-Bellman (HJB) equation
- Approximate both the Controller and the Optimal-Cost-to-Go function of the HJB by polynomials
- Under a suitable transformation the problem of approximately constructing the Controller and the Optimal-Cost-to-Go function of the HJB is transformed (approximately) to a Convex Optimization Problem!
- **ConvCD guarantees arbitrarily-close-to-the-optimal performance,**
- **provided, of course, that the *Building Dynamics* is accurately known.**

EPBs: *The PEBBLE's Approach*

Convex Control Design (ConvCD)

Two issues:

- **Scalability** (easily overcome: replace Controller polynomials by Switching Linear Elements=Mixed Mode Control)
- **Inaccuracies and variations** of the ***Building Dynamics***. ***Need for Fine-Tuning!***

EPBs: *The PEBBLE's Approach*

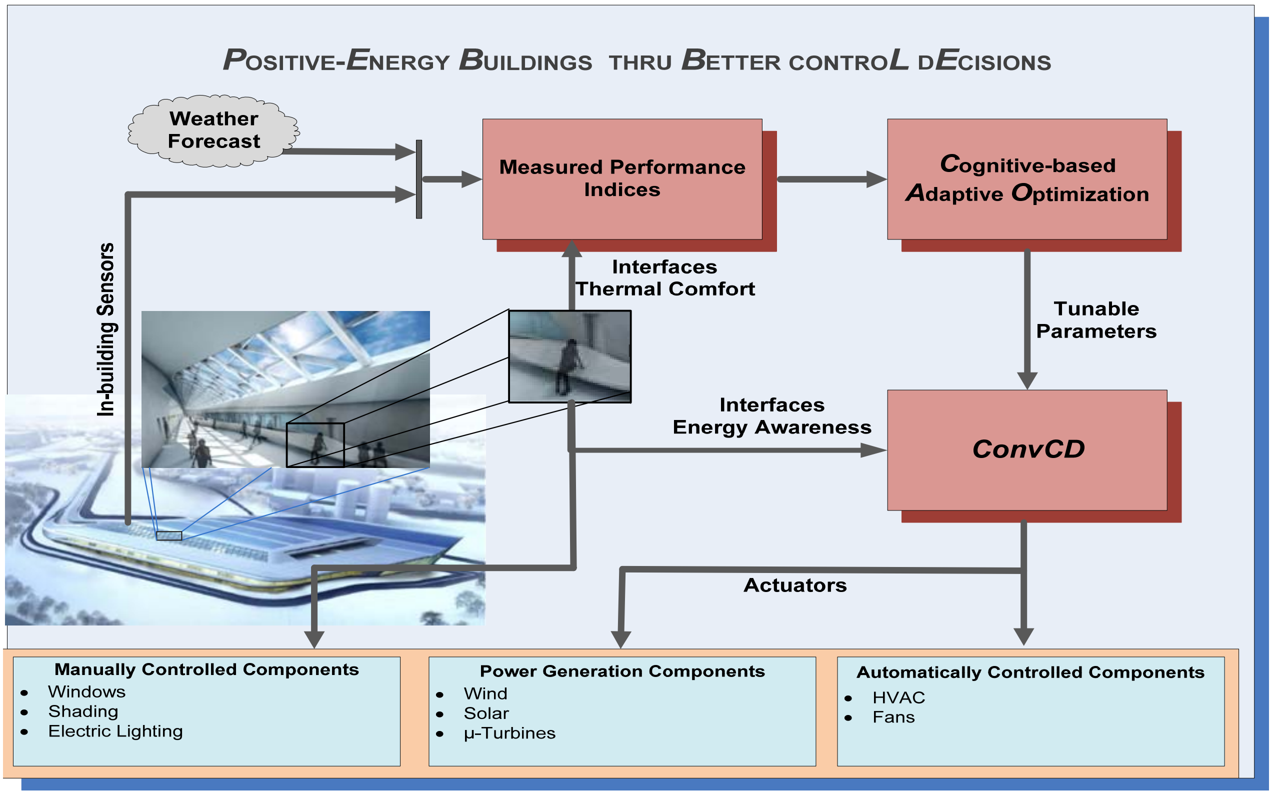
Fully-automated ConvCD Tuning (on a Daily Basis)

Based on the Cognitive-based Adaptive Optimization (CAO) algorithm for automated Fine-Tuning of Large-Scale Control Systems.

(Kosmatopoulos *et al. IEEE Trans. Contr. Syst. Techn. 2007, Automatica 2009, IEEE Trans. Neural Networks, 2009*)

- Computationally simple and scalable
- Efficient, robust and convergent performance is guaranteed both by strict mathematical arguments and extensive simulations.

EPBs: *The PEBBLE's Approach*



EPBs: *One Step Further: The AGILE Approach*

- The previous approach cannot handle efficiently situations where there are large "deviations" from the predicted ***Building Dynamics*** behavior due to e.g.
  - Sensor/Actuator Faults;
  - Large weather deviations from the forecasts;
  - Large occupants' behavior deviations from the forecasts (e.g. number of occupants currently present is significantly larger than expected);
  - Users do not obey the Controller Commands (e.g. users do not close/open a window as suggested by the Controller through the User Interface);

EPBs: *One Step Further: The AGILE Approach*

AGILE: Fault-Recovery, Self-Tunability and Re-configurability

- At each controller step:
- Detect (learn) the ***Building Dynamics*** deviations and self-tune the ConvCD controller
- or, even, re-configure the ConvCD controller (i.e. impose a new performance metric, add/remove constraints, add/remove sensors/actuators, etc).

EPBs: *One Step Further: The AGILE Approach*

Two issues:

- A new methodology is needed that allows for rapid, safe and efficient fault-recovery, self-tuning and reconfiguration.
- Allow the operator to "easily" incorporate (add/remove) performance objectives, requirements, constraints.

EPBs: *One Step Further: The AGILE Approach*

Adaptive Self-Tuning (AdaptST)

- Employs the <u>concurrent exploitation/exploration</u> adaptive scheme

  (Kosmatopoulos, *IEEE Trans. Automatic Control, 2009 and IEEE Trans. Neural Networks, in press*)

- Makes sure that the control decisions concurrently
  - explore the ***Building Dynamics*** in order to detect and identify deviations from the predicted behavior
  - They are "in the same direction" as the Optimal control actions

EPBs: *One Step Further: The AGILE Approach*

Adaptive Self-Tuning (AdaptST)

- **Guarantees rapid (exponential) fault-recovery, re-configuration and convergence to the (nearly) optimal performance**
- Combination (in a hybrid scheme) with the Multi-Mode Adaptive Control with Mixing

  (Kuipers & Ioannou, *IEEE Trans. Automatic Control, 2008)*

  to
  - Avoid computational problems
  - Allow for incorporation of "standard" tools from linear robust control

EPBs: *One Step Further: The AGILE Approach*

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.

Approach:

- "Translate" objectives, requirements and objectives 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.

EPBs: *Objectives*

Measurable Objectives

- PEBBLE: Operate EPB around 30% close to the Optimal Performance (as compared to the "no-control" case).
- AGILE: Operate EPB around 10% close to the Optimal Performance (as compared to the "no-control" case).
- AGILE: Provide Re-configuration/Fault-Recovery in less than 5 minutes.
- AGILE: Provide 40% improvements in case Re-configuration is imposed (due to major incidents/deviations) as compared to a well-fine tuned "not-Reconfigurated" controller (e.g. PEBBLE's)

AGILE goes beyond Control Systems for EPBs

- ConvCD fo general Large-Scale Systems (with emphasis on systems with intense computational requirements)
- Rapid Self-tuning, Fault-Recovery, Re-confinguration for general Large-Scale 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:
  - EPB (FIBP Building, Kassel, Germany)
  - Urban Traffic Control (Chania, Greece, the whole city's network)

AGILE
Contact Information

For inquiries regarding this Project:

send e-mail to: kosmatop@iti.gr

or check the Project Web-Site: http://www.agile-fp7.eu.

	AGILE Participants	Country
1	Centre for Research and Technology – Hellas	GREECE
2	Cyprus Institute of Technology	CYPRUS
3	The Pennsylvania State University (Penn State)	USA
4	AFCON Software and Electronics Ltd.	ISRAEL
5	Sociedad Iberica de Contsrucciones Electricas SA	SPAIN
6	Siemens AE Electrotechnical Projects and Products	GREECE
7	Fraunhofer Institute for Building Physics	GERMANY
8	Traffic Control Department – City of Chania	GREECE

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The AGILE Test Building
I. FIBP, ZENTRUM FÜR UMWELTBEWUSSTES BAUEN ZUB

Location:
Kassel, Germany.

Characteristics:
Low-energy building.
Annual energy consumption ~ 32KWh/m^2

Energy systems:
Natural night-time ventilation.
Space cooling using geothermal soil collector.
Grid-connected to renewable energy sources.
Significant thermal mass.