Optimised Embedded Distributed Controller for Automated Lighting Systems

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System of Systems (SoS)

Integrated Modelling for Building Management Systems (BMS)

Lighting Scenario

Parameterizable/Predictable Distributed (PPD) Controller

Simulation Results

Design Improvements

Summary and Future Trends
System of Systems (SoS)

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Simulation Results
Design Improvements
Summary and Future Trends
System of Systems (SoS)

The need to maintain autonomy while at the same time operating within the SoS context greatly increases the complexity of an SoS and is at the heart of the SoS architecture challenge.

SoS aim is: Getting an integrated system that is optimised better than optimising each sub-system individually
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Modelling Methodology

Model Design
- Requirements
- Systems-Model GUI
- Component model GUI

Model Repository
- Meta-Model
- Domain-Specific Models

Model Analysis
- Simulation
- Verification and Validation
- Diagnosis
- Testing
  - Charon Simulator,
  - PHAver, UPPAAL, Lydia,

Code Generation, Model Transformation

SysML

Charon Toolset, Modelica

Domain Specific Code
- Control Code
- Diagnosis Code
- Testing Code
- Embedded Code
Model Integration for BMS

- **Common System-Level Information Model**
  - Data sharing

- **Integration Mechanism**
  - Middleware

- **Benefits**
  - Sub-systems are integrated, yet
  - Retain their own standards
  - protocols
  - networks
  - Separate control environments

No such system exists today

Integrated Control Environment
What to Model?

Abstraction levels

- Discrete automata models
- Constraints models
- Purely continuous models
- Hybrid systems
- Stochastic models
- Location-aware models

Example: Building Management System (BMS)

- Discrete behaviour, e.g., Sensor presence
- High degree of concurrency
- Continuous behaviour, e.g., Heat dissipation
- Stochastic behaviour, e.g., Failure of a sensing node
Methodology for Automatic Control Code Generation

**Modelling**
- Global building modelling
  - BIM / IFC
  - Extract Control Blocks
  - SysML Structure
    - Inject Nominal Behaviour
    - Eventually Inject Faulty Behaviour
    - SysML Behaviour (e.g. FSM, AD, ...)
    - Parameter Estimation (e.g. Simulation)
  - DSML behaviour (Timed Hybrid System)

**Model-Transformation**
- Generic Meta-model
  - conformed to
  - BNF Spec. Trans. Rules
  - conformed to
- Source Meta-model (HS Language)
- Target Meta-model (Embedded Java)
- conformed to
- Target Model (Embedded Java Code)
Methodology

Scenario Specification
(i.e. Use Case Diagrams)

High Level Multi-Modelling

Analysis and Optimisation

Integrated Simulation and Validation

Code Generation

Wireless/Wired Sensor and Actuator network

Physical Plant

Requirement Specification
Integrated Simulation Platform

Hybrid/discrete Automata modelling

Preferences → Simulation Engine → Simulation Results → Environment Modeling (Sensors, Agents, ...)

Environment Modeling

Simulation Results
Hierarchical Modelling Using Charon

Top Level Design “Agents”

Blinding

Person

Behaviour Description

Light

Finite State Machine “Mode”

Default

Manual Control

Automatic

Automatic With Margin Control
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Use-case Diagram: Requirements Specification

- User
  - Enter/Exit Controlled Zone
    - Provide Luminance Preferences
    - Provide Glare Preferences
  - Set the Optimal Settings
    - When available through the Global controller e.g. using RFID

- Technician
  - Global Controller
  - Local Controller Configurations

- Blinding
- Light

- Technician
  - Global Controller
  - Local Controller Configurations

- User
  - Enter/Exit Controlled Zone
    - Provide Luminance Preferences
    - Provide Glare Preferences
  - Set the Optimal Settings
    - When available through the Global controller e.g. using RFID
One open area, 10 controlled zones.
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Parameterizable/Predictable Distributed Controller

Parameterization for local controllers (e.g. consider blinding, the occupancy priority).

- Local Optimization
- Predictions for external light, light interferences and next actuation settings.
**Distributed Optimisation Techniques**

- **Luminance Boundaries:**

![Graph showing luminance levels over time]

In order to distribute the energy consumption over all the controlled zones, luminance boundaries have been set to limit the user's preferences of exceeding 700 Lux. This will also limit the interferences between zones.

- **Tuning Process:**

If the sensed value is more than 70 Lux different than the optimal one, the actuated light is decreased by one dimming level (70 Lux) instead of the exact Lux difference. This will diminish the interferences and then speed up the stabilization process.

- **Scheduling:**

Identify the independent zones to be actuated concurrently.

- **Expected Interference:**

To avoid initial instability, an expected interference parameter is introduced using a Linear Prediction Coding (LPC) algorithm.
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Simulation Results (Single Zone)

Light Sensor Sampling Rate

Internal Light/Actuation

Blinding Actuation

External Light

The internal light controller considers the external light and light/blinding preferences

Preferences = 560 Lux, 50% Blinding
The internal light controller considers the external light, light/blinding preferences and the light interference.
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PPD improves ~ 30% comparing to Presence detection strategy
~ 9% comparing to PI Controller
QoS to the WSAN for the PPD strategy versus a centralised strategy

<table>
<thead>
<tr>
<th>WSAN QoS</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packet Loss</td>
<td>~ 53-100%</td>
</tr>
<tr>
<td>Buffer Size</td>
<td>~ 98%</td>
</tr>
<tr>
<td>Controller Duty Cycle</td>
<td>~ 34-65%</td>
</tr>
<tr>
<td>Response Time</td>
<td>~ 98-99%</td>
</tr>
<tr>
<td>Channel Throughput</td>
<td>~ 82-91%</td>
</tr>
</tbody>
</table>
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- This article has described a PPD-Controller for lighting.

Parameterization has been implemented through a global controller capable of parameter-reconfiguration of the local controllers.

Predictability is guaranteed through the prediction of light actuation (PI-Controller), interferences (LPC technique) and the external light (GASA engine).

- Next releases of the controller will integrate fault-tolerant control reconfiguration, allowing the controller to operate when faults occur.

- We intend to implement a demonstration of the developed system in the Environmental Research Institute (ERI) building, which is the ITOBO 'Living Laboratory'.
Thank you