ENERGY AWARE BUILDINGS
Modelling, Analysis & Optimization using Model Checking & Machine Learning

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UPPAAL Tool Suite

- Verification
- Optimization
- Testing
- Synthesis
- Component
- Performance Analysis
- Machine Learning

1995 CLASSIC
2001 CORA
2004 TRON
2005 TIGA
2010 ECDAR
2011 SMC
2014 STRATEGO

Green Digitalization, November 9, 2020
Gear Controller
with MECEL AB

Timed Automata Models

Magnus Lindahl
Paul Pettersson
Wang Yi
2001
Gear Controller
with MECEL AB

Requirements

GearControl@Initiate $\sim_{\leq1500} (\text{ErrStat} = 0) \Rightarrow \text{GearControl@GearChanged}$

GearControl@Initiate $\sim_{\leq1000}$

$\left(\text{ErrStat} = 0 \land \text{UseCase} = 0\right) \Rightarrow \text{GearControl@GearChanged}$

Clutch@ErrorClose $\sim_{\leq200} \text{GearControl@CCloseError}$

Clutch@ErrorOpen $\sim_{\leq200} \text{GearControl@COpenError}$

GearBox@ErrorIdle $\sim_{\leq350} \text{GearControl@GSetError}$

GearBox@ErrorNeu $\sim_{\leq200} \text{GearControl@GNeuError}$

$\text{Inv} (\text{GearControl@CCloseError} \Rightarrow \text{Clutch@ErrorClose})$

$\text{Inv} (\text{GearControl@COpenError} \Rightarrow \text{Clutch@ErrorOpen})$

$\text{Inv} (\text{GearControl@GSetError} \Rightarrow \text{GearBox@ErrorIdle})$

$\text{Inv} (\text{GearControl@GNeuError} \Rightarrow \text{GearBox@ErrorNeu})$

$\text{Inv} (\text{Engine@ErrorSpeed} \Rightarrow \text{ErrStat} \neq 0)$

$\text{Inv} (\text{Engine@Torque} \Rightarrow \text{Clutch@Closed})$

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UPPAAL Model Checking – Demo

Overview

EX> GearControl.GearChanged
EX> ( Interface.Gear5 )
EX> ( Interface.GearR )
EX> ( GearControl.GearChanged and ( SysTimer<=1000 ) )
A[] not ( GearBox.Neutral and ( Interface.Gear1 or Interface.Gear2 or Interface.Gear3 or Interface.Gear4 or Interface.GearR ) )
A[] not ( GearBox.Idle and Interface.GearN )
A[] ( Interface.GearN imply GearBox.Neutral )
A[] (( ErrStat==0 and UseCase==0 and SysTimer>=900 ) imply ( GearControl.GearChanged...))
EX> ( ErrStat==0 and UseCase==0 and SysTimer>899 and SysTimer<900 and not ( Gear... )
A[] (( ErrStat==0 and UseCase==0 and ( SysTimer<150 ) ) imply not ( GearControl.Gear...))

Query

EX> GearControl.GearChanged

Comment

P1. It is possible to change gear.
SMART HOUSES

- Automatic control of a number of functions in a house.
- Formulated as a game between environment and the controller.
- Automatic synthesis of improved, optimal and personalized control strategy.
- From abstract game strategies to concrete code running on real hardware.
AI and Machine Learning

Monte Carlo Tree Search

Reinforcement Learning

Alpha Go
OPTIMAL FLOOR HEATING
Floor Heating Scenario

- Each room has a hot water loop that can be opened/closed.
- Loops are controlled via activating/deactivating valves.
- Rooms equipped with wireless temperature sensors (report every 15 minutes).
- Each room has its user-defined target temperature.

**Control Task:**
Maintain room temperatures as close as possible to target temperatures.
1-Room / 1-Window Game

const double Tg = 21.0; // room temp. goal
const double Te = 15.0; // environment temp.
const double H = 0.04; // power of heater
const double Aclosed = 0.002; // heat loss when window closed
const double Aopen = 0.004; // heat loss when window open
const int P = 15; // heater switching period
const int h = 60; // 1 hour = 60 time units
Find strategy that minimizes expected discomfort:

\[ D(H) = \int_{t=0}^{t=H} \left( T(t) - T_g(t) \right)^2 dt \]
// Optimal Control Strategy for 15 Periods
strategy opt = minE (D) [<=15*P]: <> t=15*P
simulate 10 [<=15*P] { T, Window.Open15, Room.HeatOn+17 } under opt
simulate 10 [<=15*P] { D } under opt
E[<=15*P; 10](max:D) under opt

Query
simulate 10 [<=30*P] { D }

Comment
demonstration how the distance function behaves with random controller
Full Floor Heating Case

**CHALLENGE**
$2^{11}$ valve configurations at each 15 minutes

**SYNTHESIS BY LEARNING**
ON-LINE SYNTHESIS
COMPOSITIONAL SYNTHESIS
# Full Floor Heating Case

## 3 day scenario

### Evaluation of under modified parameters (0-20%)

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<th>Energy</th>
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FLEXIBILITY & FLEX OFFERS
The basic idea
Sun implies a cooling demand and simultaneously provide (the necessary?) energy to provide the cooling.
FLEX OFFERS

Probabilistic flex-offers found from strategies for minimizing (maximizing) kWh\_buy

\[
\text{strategy min(max)kWh = min(max)E (kWh\_buy) [<=H]: <> (i - offset) == H}
\]
Probabilistic flex-offers found from strategies for minimizing (maximizing) $kWh_{buy}$

Strategy:

$$\text{strategy } \min(\max) kWh = \min(\max) E (kWh_{buy}) \leq H: <> (i - \text{offset}) == H$$
MORE GAMES USING UPPAAL

- Traffic Control
- Zone-based climate control pig-stables
- Profit-optimal, energy-aware schedules for satellites
- Optimal control of heat-pumps
- Personalized light control in home automation
- Safe and energy optimal control of hydraulic pumps
- COVID19

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