Safe and near optimal controller synthesis for Stochastic Hybrid Games

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Thesis submitted to the
Department of Computer Science
in partial fulfillment of the requirements for the degree of
Master in Computer Science.

Universidad Católica San Pablo – UCSP
July of 2021 – Arequipa – Peru

To my parents, Mario and Maria, who never stop giving of themselves in countless ways. To my brothers and sister, who encourage and support me.

Chapter 1

Safe and near optimal controller synthesis

In this part, we choose as a case of study an *Hybrid Solar Water Heating*, because this system link up important condition to implement the methodology described in this work. Firstly we have agents, who interact with the system, adding uncontrollables modes of operations also some controllable variables in the system that allow to model as stochastic hybrid game.

The first part is about mathematical modelling using heat transfer theory and fluids dynamics to get temperature dinamics and then to define the parameters that determine the system with some assumptions to facilate the analysis.

1.1 Solar Water Heating Case study

Setup system:

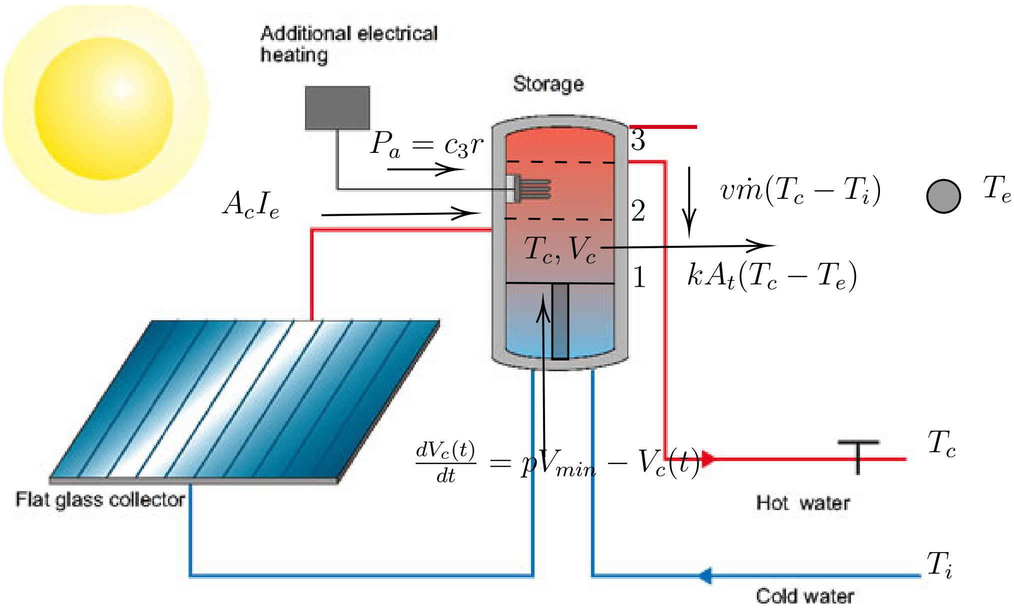

Figure 1.1: Solar Water Heating diagram

The energy inside of the container is calculated as a control volumen, an abstract region which experiment power input and output, doing a energy balance is obtained the dynamical either volumen or temperature as described in 1.1 and 1.2.

$$C_e M_c(t)\frac{d}{dt}T(t) = A_c I_{env}(t) + P_{aux} - vC_e\dot{m}(T(t) - T_{in}(t)) - k_c A_t(T(t) - T_{env}(t)) + rQ \tag{1.1}$$

$$\frac{d}{dt}M_c(t) = \rho\frac{d}{dt}V(t) = \rho(pV_{min} - V(t)); \tag{1.2}$$

States			
Variable	Description	Initial Value	Units
E	Energy consumption	0.0	J
V	Container Volumen	0.13	m^3
T	Container Temperature	50.0	°C
Constants			
Variable	Description	Value	Units
C_e	The factor heat of the water in	4186	$\mathrm{J\,°C^{-1}\,kg^{-1}}$
$\dot{m}$	Mass flow rate input/output	0.1	$\mathrm{kg\,s^{-1}}$
M_c	the mass of the container in	100	kg
A_c	Area of colector in	1	m^2
A_t	Area of total of surface in	5.56	m^2
k_c	Conduction coeficient	16	$\mathrm{W\,m^{-1}\,°C^{-1}}$
P_{aux}	Auxiliary heat power in	1000	W
Input values			
Variable	Description	Space values	
v	Controllable action to release water	$\{0,1\}$	
r	Controllable action to heat	$\{0,1\}$	
p	Uncontrollable action to change capacity water	$\{1,2,3\}$	
Disturbances			
Variable	Description	Range	Units
$T_{in}(t)$	the temperature of water input/output in	$[20-25]$	°C
$I_{env}(t)$	the irradiance in	$[0-920]$	$\mathrm{W\,m^{-2}}$
$T_{env}(t)$	the outside temperature in	$[0-16.5]$	°C

Table 1.1: Parameter values.

Hybrid Solar Water Heating as a Sthocastic Hybrid Game. The hybrid solar water heating scenario with 12 modes of operations is defined like this: $\mathcal{G}_{n,m} = (\mathcal{C}, \mathcal{U}, \mathcal{X}, \mathcal{F}, \delta)$, where the controller $\mathcal{C}$ has a finite set of controllable modes, given by resistance state $r \in \mathbb{B}$ and piston position $p \in \{1, 2, 3\}$. The environment $\mathcal{U}$ has a finite set of uncontrollable modes $v \in \mathbb{B}$, that means the valve state for opening/closing water aperture. We assume that $\mathcal{U}$ given δ can switch among modes with equal probability at every period. The state variables in $\mathcal{X}$ are given by $\{T, E, V\}$, container temperature, energy used and container volumen respectively.

Given the container temparature and volume, a controllable modes $r \in \mathbb{B}$ and $p \in \{1, 2, 3\}$ and uncontrollable mode $v \in \mathbb{B}$ and a time delay τ.

$$\begin{aligned} \frac{d}{dt}T(t) = \frac{1}{V(t)}[&-c_1(T(t) - T_{env}(t)) - pc_2(T(t) - T_{in}(t)) \\ &-fc_3(pV_{min} - V(t))(T(t) - T_{in}(t)) + c_4 I_{env}(t) + rc_5] \end{aligned} \tag{1.3}$$

$$\frac{d}{dt}V(t) = pV_{min} - V(t); \tag{1.4}$$

$$\frac{d}{dt}E_{used} = rc_3; \tag{1.5}$$

The equation 1.3 has some constants $\{c_1, c_2, c_3, c_4\}$ this parameters are computed with the parameteres defines in table 1.1 for specific Hybrid Solar Water Heating are equal to $\{2.44e^{-5}, 4.77e^{-6}, 0.0024, 0.01\}$ respectively.

1.2 Simulations and Results

Solaris Data and prediction data The Figure environment ”floats” to find an optimal position on the page. When you begin a figure, you can use the options [htbp!] to specify whether the figure should go ”here”, the ”top” of this page, the ”bottom” of this page, or a special ”page” reserved for floats. LaTeX, in its infinite wisdom, will sometimes prevent you from putting a figure in an ”ugly” place, but.

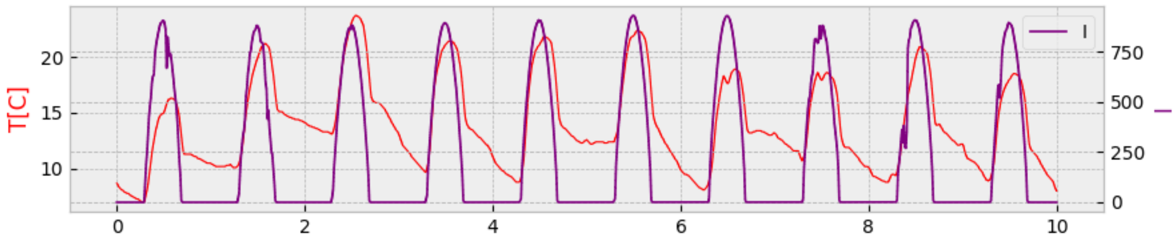

Figure 1.2: An example image not including a Wombat

Data preparation. The Figure environment ”floats” to find an optimal position on the page. When you begin a figure, you can use the options .

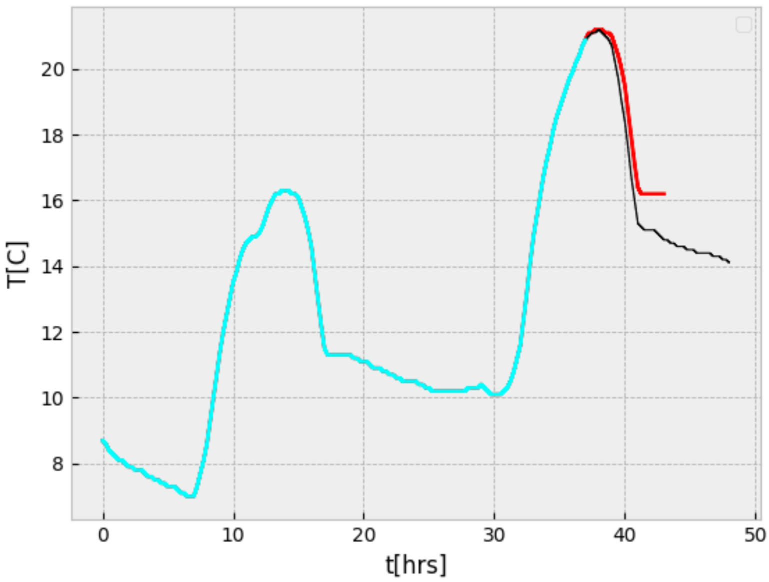

Figure 1.3: An example of prediction using ARIMA forecaster

Experiments [floor heating] Regarding our experiments, we have two major components: a simulator written in PYTHON and a number of controllers, including the ones produced by UPPAAL STRATEGO. The simulator implements the solar water heating hybrid game $\mathcal{G}_{n,m}$. For our experiments, in the simulator we fix a time horizon H of 75 minutes with a period P of 5 minutes. As in the real house, every 15 minutes, the simulator outputs the current room temperatures T which are read by the controller. Subsequently, the controller inputs the control valves V which are used by the simulator for the next 5 minutes. The house has a desired temperature T^g and alpha parameters which denotes the importance to optimize either target or energy consumption. Our goal is to optimize the comfort in the water consumption and also energy consumption as a cost function. To define this cost function subject to controller (strategy) σ and $\mathcal{G}_{n,m}$ of the form $\pi = \gamma_0 \xrightarrow{t_1} \gamma_1 \xrightarrow{t_2} ... \xrightarrow{t_{k-1}} \gamma_{k-1} \xrightarrow{t_k} \gamma_k$ where $k = H/P$ is the number of control steps in the run π. Let $T_i(\gamma_j)$ denote the container temperature T_i at configuration γ_j. Then the const function is defined by

$$dist(\pi) = \alpha(E) + (1 - \alpha)(T - T_g) \tag{1.6}$$

In our experiments, we evaluate a number of different controllers. The simulator uses the distance function dist to compare the different controllers.

Controllers. In the following we introduce a number of controllers which we use in out experiments. We present the current controller operating in the house, two controllers proposed by engineers and the controllers synthetized using online synthesis and UPPAAL-STRATEGO.

Bang-Bang Controller. The bang-bang controller is currently running in the physical house and after each reading of container temperature T, it simply switch the resistor ON of container where $T < T^g$ and leaves the reaiming switch OFF.

Greedy controller

Safe Controller with Patterns. The Figure environment "floats" to find an optimal position on the page. When you begin a figure, you can use the options [htbp!] to specify whether the figure should go "here", the "top" of this page, the "bottom" of this page, or a special "page" reserved for floats. LaTeX, in its infinite wisdom, will sometimes prevent you from putting a figure in an "ugly" place, but you can (sort of) override its decision using the "!" option. When you haven't used any option, the environment assumes that you provided [tbp], and it's choosing to put the figure at the top of the page, above where your section goes.

Statego Online Controller. The Figure environment "floats" to find an optimal position on the page. When you begin a figure, you can use the options [htbp!] to specify whether the figure should go "here", the "top" of this page, the "bottom" of this page, or a special "page" reserved for floats. LaTeX, in its infinite wisdom, will sometimes prevent you from putting a figure in an "ugly" place, but you can (sort of) override its decision using the "!" option. When you haven't used any option, the environment assumes that you provided [tbp], and it's choosing to put the figure at the top of the page, above where your section goes.

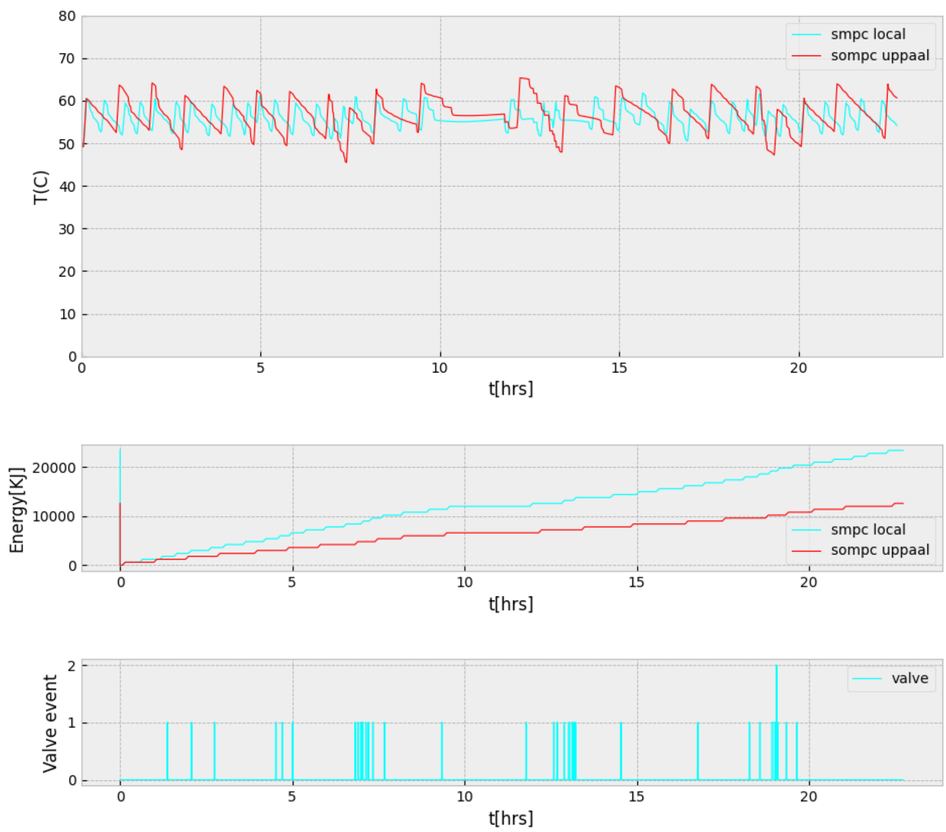

Figure 1.4: An example image not including a Wombat

Safe and Near Optimal Controller.

Evaluation Scenarios

Controller Evaluation

Bibliography