Cyber-Physical Home System for Temperature control of a Room

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Introduction

The smart control of thermal environment is essential to reach a good level of comfort. In this presentation, A HTC system is explained in which real-time temperature in a room is controlled real-time.[1] In particular, room temperature is correlated with two actuators (air-conditioner and window) used for both heating and cooling mode which can modified it depending on the situation. The control of room heat is a challenging task for several reason:

1. External weather and climate can be used to control the internal temperature.
2. The time in which we reach our goal is very important to have an efficient system.
3. The dynamic of changing the environmental conditions.

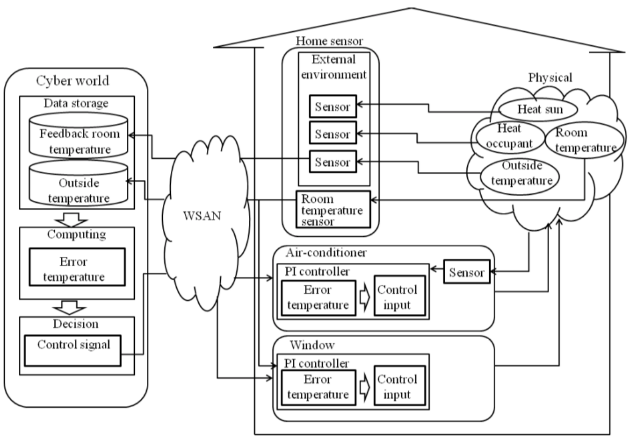

Figure 1: HTC System Architecture

[1]For the sake of simplicity, I take into account only temperature and not other factors like humidity, lights etc..

1 HTC System Architecture

Figure 1 shows how cyber and physical world are defined. it is used a communication network called WSAN (wireless sensor and and actuator network) in which there are two components: sensors and actuators. The sensors in the physical side send the information of the environment to the controllers. The actuators perform the corresponding task according to the control signal sent by the controllers to make the required changes of physical system.
Below in figure 2 a diagram of how our HTC system works is presented. the room temperature parameter is sensed by the sensors. These sensed data are sent to the PI and supervisory controller. PI controllers compute the appropriate control signal to be sent to the corresponding actuators, while the supervisory controller decides which actions should be taken, based on the changes of outside temperature and the feedback room temperature . In this way, *the room temperature is being controlled and monitored to approaching the desired room temperature.*

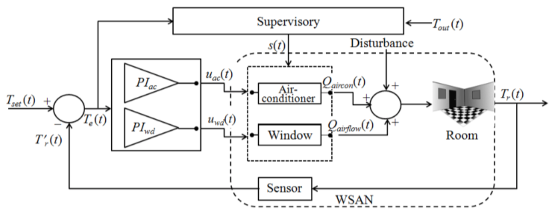

Figure 2: HTC System Block diagram

2 Mathematical representation

In this section We present a possible way to model our HTC system. We consider three types of change that influence room temperature, even if it is possible to take into account several relevant factors:

1. Heat change from the air-conditioner (Q_{aircon}).
2. Heat change from opening window ($Q_{airflow}$).
3. Heat change due to temperature difference between inside and outside through window only (Q_{dth}).

The dynamic room temperature can be represented as:

$$T_r(t) = \frac{1}{\beta} Q_{all} + T_r(t-1) \tag{1}$$

where

$$Q_{all} = Q_{aircon} + Q_{airflow} + Q_{dth}$$
$$\beta = \rho_{air} V_{room} C_p$$

where ρ_{air} is air density, V_{room} is room volume and C_p is specific heat capacity air. All we have to do is define the three different types of heat change.

Air-condition system

For what concerns air-condition systems, we can simply express the sensible heat in the heating or cooling system of air as follow

$$\mathrm{Q}_{aircon} = 1.08 \times CFM\,(T_{sa} - T_r) \tag{2}$$

where CFM is air volume flow and determines how much work the air-conditioner does, T_{sa} is the setting temperature of air-conditioner and T_r is the room temperature.

Window system

When the window is opened, the heat generation of a space from outside to inside by the natural ventilation is given by

$$\mathrm{Q}_{airflow} = V_{airflow} C_p \rho_{air}\,(T_{out} - T_r) \tag{3}$$

where T_{out} is the outside temperature, and $\mathrm{V}_{airflow}$ is the ventilation rate required to remove heat from the occupied space and it is equal to

$$\mathrm{V}_{airflow} = \mathrm{A}_{op}\mathrm{c}_d\nu_{air}$$

where A_{op} is surface area of window opening, c_d is effectiveness of air, and ν_{air} is air velocity leaving the opening window.

Heat gain through the glass

Heat gain through the glass is due to the difference between outside and inside temperature and it can be expressed by the following formula

$$\mathrm{Q}_{dth} = \mu_g A_g\,(T_{out} - T_r) \tag{4}$$

where μ_g is the u-value for glass and A_g is the entire surface area of glass window.

3 Hybrid System

As we are dealing with hybrid system, there are both continuous and discrete behaviours; in fact the room temperature is continuous dynamics, whereas state transition has discrete nature. The continuous part dynamics are modeled using differential equations, while the discrete-event dynamics are modeled by finite state automata. As it is shown in figure 3, hybrid automation can be represented as follow:

1. States = $\{S_{aoff,wcl}, S_{aon,wcl}, S_{aoff,wop}\}$
2. Inputs = $\{$*error temperature*,*outside temperature*$\}$
3. Outputs = $\{$ *Air-con*$_{on}$,*Air-con*$_{off}$, *Window*$_{open}$, *Window*$_{closed}\}$

The following differential equations govern the changes of the room temperature in the three different states.
When the system is in $S_{aoff,wcl}$, the room temperature changes according to the following formula

$$\frac{dT_r}{dt} = \frac{1}{\beta}\mathrm{Q}_{dth} \tag{5}$$

When the system is in $S_{aon,wcl}$, the room temperature changes according to the following formula

$$\frac{dT_r}{dt} = \frac{1}{\beta}\left(\mathrm{Q}_{aircon} + \mathrm{Q}_{dth}\right) \tag{6}$$

When the system is in $S_{aoff,wop}$, the room temperature changes according to the following formula

$$\frac{dT_r}{dt} = \frac{1}{\beta}\left(\mathrm{Q}_{airflow} + \mathrm{Q}_{dth}\right) \tag{7}$$

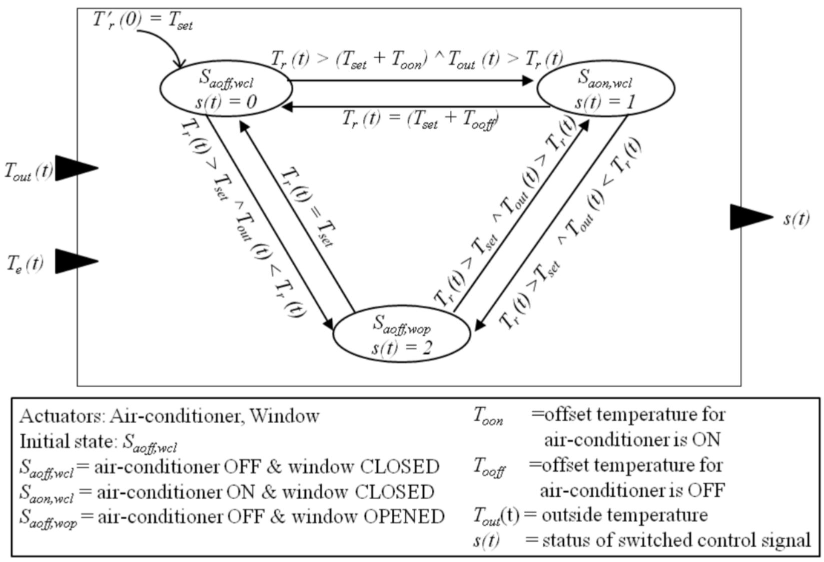

Figure 3: Hybrid automata of our system. In this figure T_{oon} represents the offset temperature.

PI Controller

PI controller consists of proportional and integral elements and it is widely used in feedback control processes. It is described as

$$u\left(t\right) = K_p e\left(t\right) + K_i \int e(t)df \tag{8}$$

PI controller has perfect effect in small-scale and regulate near the balance setpoint, where its integral action can finally cancel the error. I consider the air-conditioner using a conventional PI controller and it varies the speed of the compressor motor, and controls the refrigeration load. For window, the PI controller controls the area of window opening.

4 Requirements

For what concern this type of problem, typical requirements could be the following ones:

1. When the office opens, the temperature has to reach an acceptable situation before the first employee arrives (around 8 a.m.).
2. When the room is occupied, the indoor temperature has to be as closed as possible to the desired temperature $\mathrm{T_{set}}$: it means that it has to stay in a very tiny interval $[\mathrm{T}_{set} - \mathrm{T}_{offset}, \mathrm{T}_{set} + \mathrm{T}_{offset}]$[2].
3. During the night for economic reasons the window must be closed and the air conditioner off.

In terms of STL required situations could be synthesized in the following way:

$$\mathbf{G}_{[0,6h]\cup[18,24h]}\left(s\left(t\right)=0\right) \tag{9}$$

$$\mathbf{F}_{[6,8h]}\left(\mathrm{T}_{set} - \mathrm{T}_{offset} < \mathrm{T}_r\left(t\right) < \mathrm{T}_{set} + \mathrm{T}_{offset}\right) \tag{10}$$

$$\begin{gathered} step\left(y,t\right) := \left|y\left(t+\tau\right) - \mathrm{T}_{set}\right| < \mathrm{T}_{offset} \\ \mathbf{G}_{[6,8h]}\left(step\left(\mathrm{T}_r,t\right) \Longrightarrow \mathbf{G}_{[\tau,8h]}\left|\mathrm{T}_r\left(t\right) - \mathrm{T}_{set}\right| < \mathrm{T}_{offset}\right) \end{gathered} \tag{11}$$

$$\mathbf{G}_{[8,18h]}\left(\varphi_{room} \Longrightarrow \mathrm{T}_{set} - \mathrm{T}_{offset} < \mathrm{T}_r\left(t\right) < \mathrm{T}_{set} + \mathrm{T}_{offset}\right) \tag{12}$$

which avoid uncomfortable situation described below:

$$\mathbf{F}_{[8,18h]}\left(\varphi_{room} \Longrightarrow \mathrm{T}_r\left(t\right) > \mathrm{T}_{set} + \mathrm{T}_{oon}\right) \qquad (hot \quad situation) \tag{13}$$

$$\mathbf{F}_{[8,18h]}\left(\varphi_{room} \Longrightarrow \mathrm{T}\left(t\right) < \mathrm{T}_{set} - \mathrm{T}_{oon}\right) \qquad (cold \quad situation) \tag{14}$$

where φ_{room} stays for *room is occupied by someone.*

In order to perform falsification with respect on one of previous property we could follow a naive way: we just try to minimize the robustness over N iterations by considering random samples (or eventually samples with respect some specific grids) on control parameters (error temperature,outside temperature). In particular, If I can find some control parameters for which the value is negative, then it means that we have been able to falsify the specific property.

[2] this request therefore provides for the presence of a sensor suitable for checking the presence of a person

Conclusion

In this project, we modeled a system with the purpose of controlling the real-time temperature of a room in a building. Of course, A lot of simplifications are performed: Mathematical model should take into account more things respect than we we took in account previously. What we wanted to show is the theoretic procedure to model a HTC system using a Cyber-Physical approach. We first described the HTC architecture, giving a simple mathematical description of the system, then we introduced the hybrid system relative to this model and at the end we analyzed some usual requirements.