PID Controller tuning and implementation aspects for building thermal control

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Introduction

- The deployment of Building Energy Management Systems (BEMS) has set new research goals:
  - The design of algorithms which:
    - Minimize power consumption.
    - Ensure indoor comfort conditions.
  - Adaptation and tuning of those algorithms in order to be effective and robust.
  - Intelligent uses of the available infrastructure.

State of the art

- **Technical University of Crete / Technical Educational Institute of Crete**
  - Design, tuning and comparison of Fuzzy and conventional PID controllers for HVAC applications.
- **Qu and Zaheeruddin**
  - Adaptive PI controller for HVAC applications, using the transformation of loop-shaping tuning rules to discrete-time tuning rules.
- **Wang,Lee, Fung, Bi and Zhang**
  - High performance PID controller for a range of linear self-regulating processes.
- **Huang and Lam**
  - Illustration of a genetic controller approach for the tuning of conventional PID controller rules.

Formulation of the problem

- Design of conventional PID controllers for the adjustment of indoor conditions of a university laboratory using a HVAC installation.
- Tuning of the controllers in order to minimize power consumption.
- Application and test of the algorithms in order to check their function, stability and robustness in the presence of external disturbances.

The conventional PID controller

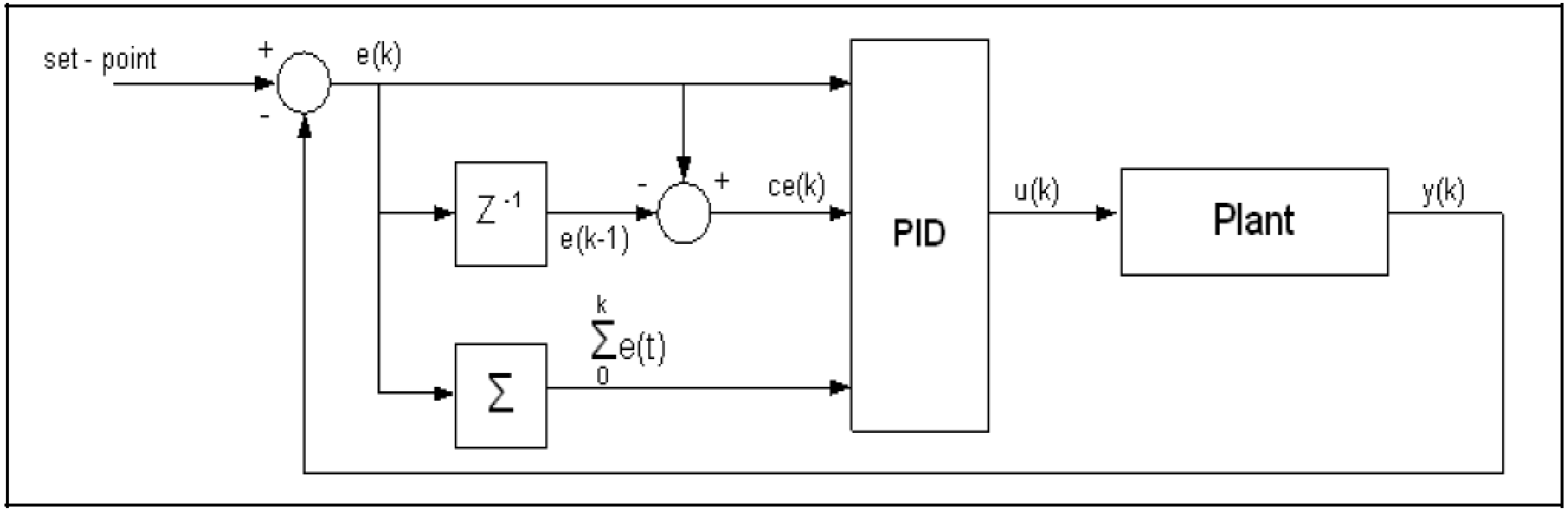

Fig.1, Conventional PID Controller Block diagram

The conventional PID controller transfer function for the discrete time domain is given below:

$$u(t) = K_c\left[e(t) + \frac{T_o}{T_i}\sum_{i=o}^{k-1} e(i) + \frac{T_d}{T_o}(e(k) - e(k-1)) \right]$$

Where: Ti=Kp/Ki (integral constant), Td=Kd/Kp (derivative constant), Kc $\approx$ Kp

Kp (proportional gain), Ki (integral gain), Kd (derivative gain)

Tuning of PID controller

- The measured process does not indicate oscillatory behavior.Therefore, we use the process reaction curve method proposed by Ziegler and Nichols.
- The open loop unit step response is measured and then approximated by a curve.
- The tangent, in the point of the curve where the first derivative receives its maximum value is drawn.
- Delay time: $\tau_d = t_1 - t_0$

  Response time: $T = t_2 - t_1$

  Gain: $K = \dfrac{y_\infty - y_0}{u_\infty - u_0}$

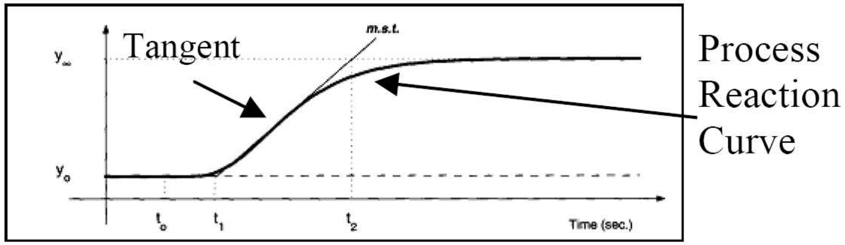

Fig.2, Process unit step response

Controller	Parameters		
	K_c	T_i	T_d
P	$\dfrac{T}{K\tau_d}$		
PI	$\dfrac{0.9T}{K\tau_d}$	$\dfrac{\tau_d}{0.3}$	
PID	$\dfrac{1.2T}{K\tau_d}$	$2\tau_d$	$0.5\ \tau_d$

Table 1, Controllers' parameters using process reaction curve method

Extraction of PID parameters

- A unit set input was applied to the process (air-conditioning units set to full power).
- The response $Temp_{in}$ of the process (internal temperature in centigrade scale) was measured accordingly and is depicted to the figure beside.
- Each sample corresponds to a two minute period
- The tangent was drawn at the point of inflection.
- The system reached its steady state after 120 minutes (steady state temperature was measured to be 22 ℃
- Afterwards the gain K_c and the integral T_i and derivative constant T_d were calculated using the equations proposed by Ziegler and Nichols and the results are shown on the table beside

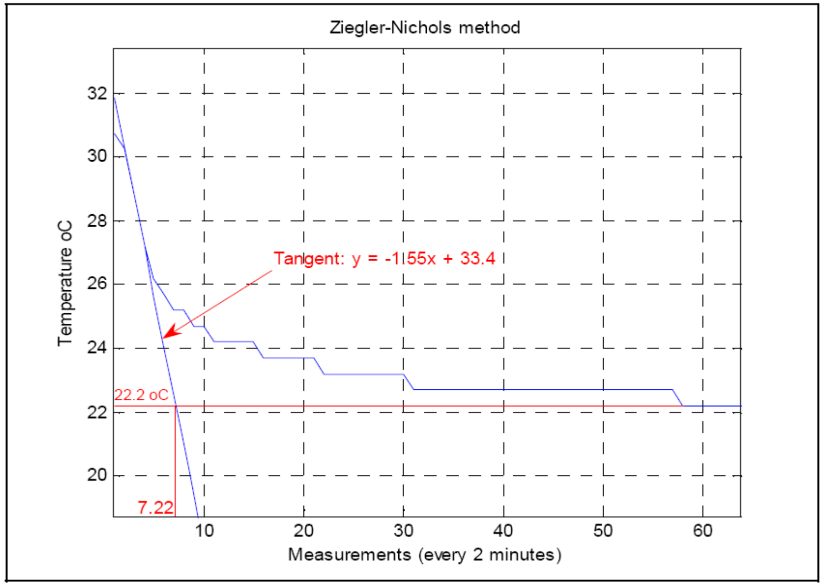

Fig. 3, Internal Temperature Curve with tangent at the point of inflection.

	K_c	T_i	T_d
P	0.7275		
PI	0.6547	6.6666667	
PID	0.8729	4	1

Table 2, Calculated gain, derivative and integral constants for P/PI/PID controllers

Tuning of PID Controller

- The transfer function of the PID controller takes the following form:

$$u(k) = 0.8729\left[e(k) + \frac{T_o}{4}\sum_{i=o}^{k-1} e(i) + \frac{1}{T_o}(e(k) - e(k-1)) \right]$$

- The sampling time T_0 *(same with the system control period)* was set to 8 minutes in order to avoid mechanical wear to the air-conditioning units which function using Pulse Width Modulation (PWM) on an on-off basis. Thus, the transfer function of the controller becomes:

$$u(k) = 0.8729\left[e(k) + \frac{8}{4}\sum_{i=o}^{k-1} e(i) + \frac{1}{8}(e(k) - e(k-1)) \right]$$

Experimental Results

- The measured system variables were:
  - Internal temperature (℃)
  - Mean Radiant Temperature (MRT) (℃)
  - External Temperature (℃)
  - Predicted Mean Vote (PMV) ([-3,3])
  - Air-conditioning Units duty cycle (0-100%)
- The experiments took place during last summer and lasted two days.

Experimental Results (II)

- The system output assigned to the Internal Temperature *Tin* and is depicted on Figure 4 beside.
- The set point was selected to be 28 ℃ and corresponds to the red line on the figure.
- The system reaches the set point area in 6 system cycles (48 minutes).
- The mean Internal Temperature was calculated to be 28,073 ℃ yielding a mean error of 0,26%.
- The oscillations around the set point are due to external disturbances (open doors and windows) and due to the on-off operation of the air-conditioning units.
- The oscillation amplitude was does not exceed 2,5% of the set point value (less than 0,5 ℃).

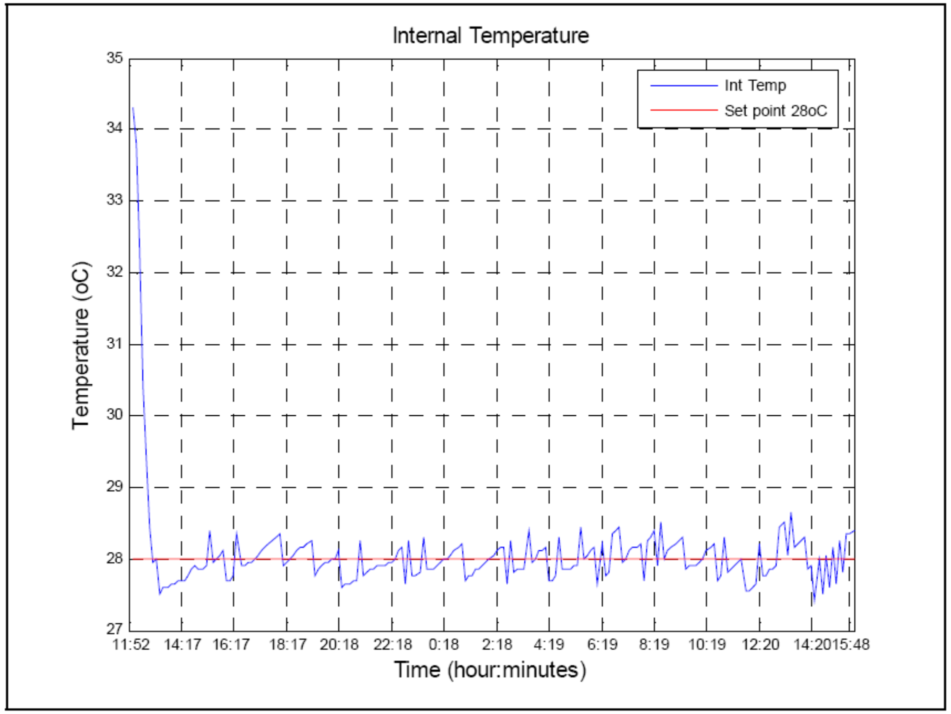

Fig.4, Process closed loop response

Experimental Results (III)

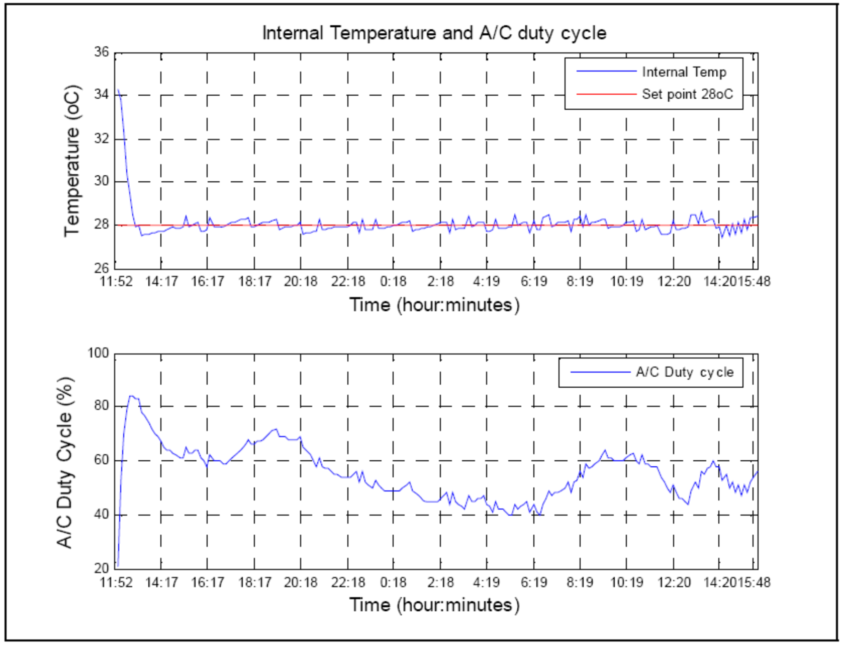

Fig.5, Internal Temperature along with A/C units duty cycle

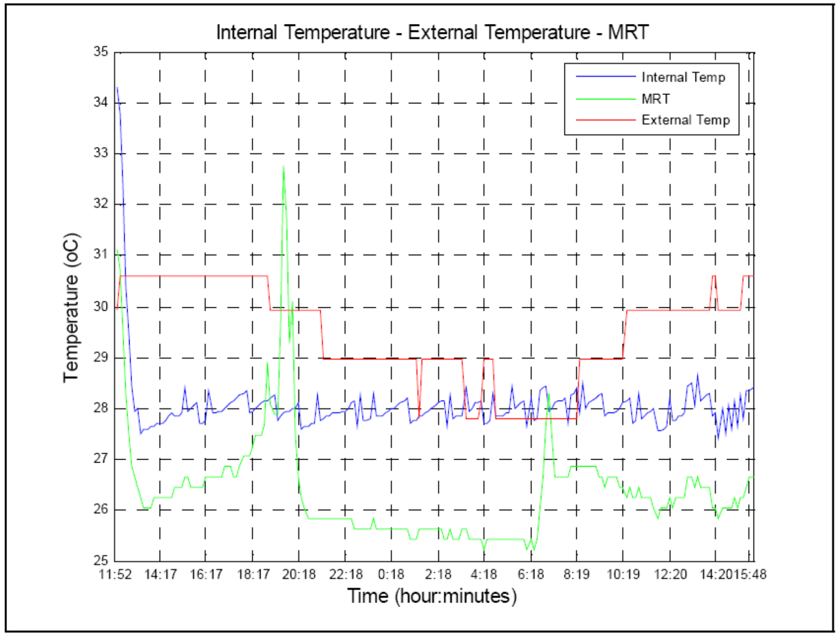

Fig.6, Plot of Internal Temperature, External Temperature and Mean Radiant Temperature

End of presentation

Thank you

Questions and comments are welcome.