# A DYNAMIC CONTROL MODEL TO IMPROVE THE RESPONSE SPEED FOR AN AIR-CONDITION SYSTEM

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## ABSTRACT

A procedure for deriving a dynamic model of an HVAC system was described in this paper. The system consists of a zone, cooling coils and fan. Room thermal balance model and dynamic model of HVAC control system components including sensor, cooling coils and ducts, were established. These models accurately predicted the effect of inlet air temperature, airflow rate, and inlet chilled water temperature on the room temperature. During closed loop control of output air temperature, chilled water flow rate was used as a control input. Vriable water volume (VWV) was control by Fuzzy adaptive control (FA) combined with proportional integral derivative (PID) control algorithms (FA-PID). Computational simulations of two different control algorithms PID and FA-PID control were carried out in toolbox Simulink of Matlab. The fuzzy parameters were carefully tuned to produce less oscillatory responses. The results showed that the system based on FA-PID control is capable of controlling the disturbance efficiently with less time lag and small error than PID control.

## INTRODUCTION

The dynamic behavior of a Heating, Ventilation and Air Conditioning (HVAC) system has great impact on indoor air quality, as well as on power and energy consumption. The design of successful controllers for HVAC systems primarily depends on the availability of good dynamic models of the systems and mathematical equations that describe its behavior. In addition to the models, efficient control methods also play an important role in the transient response of the system. In order to optimize the operation of HVAC system, so it is necessary to establish models for each component and find a reasonable control method.

Recently, HVAC dynamic models were studied by many researchers. Maxwell et al. [1] developed an empirical model of chilled water coil and used it to predict the system response to inputs with Proportional (P), Proportional Integral (PI), and Proportional Integral Derivative (PID) control algorithms. An empirical nonlinear model of a hot-water-to-air heat exchanger loop that is used in developing nonlinear control principle was developed by Underwood and Crawford [2]. This model accurately predicted the effect of inlet air temperature, air flow rate, and inlet water temperature during closed control of output air temperature using water flow rate as a control input. A procedure for deriving a dynamic model of an air-conditioned room based on the energy conservation laws was described Kasahara et al. [3,4]. A dynamic model of an HVAC system that consists of a zone, heating coil, cooling and dehumidifying coil, humidifier, ductwork, fan, and mixing box was established by Tashtoush et al. [5].

In order to control the disturbance with fewer time lags and small error, it is necessary to acquire a more accurate model and efficient control method. A dynamic model of an HVAC system is established in this paper. Fuzzy adaptive control (FAC) combined with proportional integral derivative (PID) control algorithms (FA-PID) is used to improve the transient response of the system.

## MATHEMATICAL MODEL

The major components in the system model include an air-conditioned room and air-handling unit (AHU) which is composed of chilled pipe, filter, fan, cooling and dehumidifying coil and air duct as shown in Figure 1.

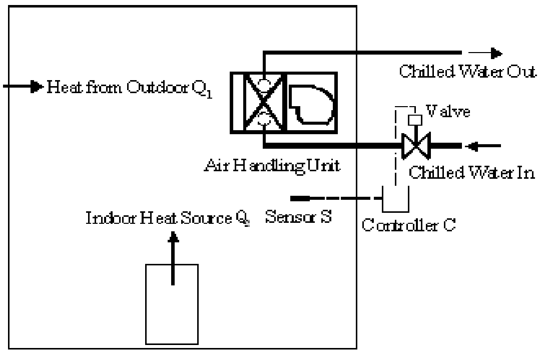


**Figure 1** A schematic diagram of HVAC system

As shown, In summer, the return air enters AHU and flows across a cooling coil through which the chilled water circulates. The moist air condenses, and saturated moist air exits the cooling coil into the zone to satisfy delivery condition. In the zone, the thermostat senses the temperature of the zone and the signal is responded to the controller to control the chilled pipe valve to control the flow rate of chilled water. This study will only discuss the control process in summer season.

**The room's model**

The room is a complex thermal system. In order to establish the room's model simply, it is assumed that the air in the room is fully mixed and the room's temperature is uniform. In addition, the effect of the North wall on the room temperature is assumed to be the same as the effect of the South wall. The East and the West wall are the same. The ground has no effect on the room temperature. The density of the air is constant. The indoor heat source includes heat from people, lights and indoor facilities.

According to above assumptions, energy equations are in the following [5].

$$C_z \frac{dT_z}{dt} = f_{sa}\rho_{sa}C_{pa}(T_{sa}-T_z)+2U_{w1}A_{w1}(T_{w1}-T_z) + 2U_{w2}A_{w2}(T_{w2}-T_z)+U_R A_R(T_R-T_z)+q(t) \quad (1)$$

$$C_{w1}\frac{dT_{w1}}{dt} = U_{w1}A_{w1}(T_z-T_{w1})+U_{w1}A_{w1}(T_o-T_{w1}) \quad (2)$$

$$C_{w2}\frac{dT_{w2}}{dt} = U_{w2}A_{w2}(T_z-T_{w2})+U_{w2}A_{w2}(T_o-T_{w2}) \quad (3)$$

$$C_R\frac{dT_R}{dt} = U_R A_R(T_z-T_R)+U_R A_R(T_o-T_R) \quad (4)$$

$$V_z\frac{dW_z}{dt} = f_{sa}(W_{sa}-W_z)+w(t)/\rho_{sa} \quad (5)$$

Equation (1) presents that the rate change of energy in the room is equal to the difference between the energy transferred to the room and the energy removed from the room. While in equation (2)-(4), the rate change of energy through walls is equal to the energy transferred through walls due to temperature difference between indoor and outdoor air. In equation (5), the rate change of moisture content in the workshop is equal to the difference between the vapor added to and removed from the workshop.

**The temperature sensor model**

The function of the temperature sensor is to measure the temperature in the workshop and to give feedback signal to the control system in order to enhance the performance of the system. The math description is as follows [5].

$$\tau_{se}\frac{dT_{in}}{dt}+T_{in}=\tau_{se}T_{out} \quad (6)$$

where, $\tau_{se}$ is time constant, $T_{in}$ is measured temperature, $T_{out}$ is temperature out of the sensor.

**The humidity sensor model**

The function of the humidity sensor is to measure the temperature in the workshop and to give feedback signal to the control system in order to enhance the performance of the system. The math description is as follows [5].

$$\tau_{sd}\frac{d\varphi_{in}}{dt}+\varphi_{in}=\tau_{sd}\varphi_{out} \quad (7)$$

**The cooling and dehumidifying coil model**

The model of cooling and dehumidifying coil is also based on the energy and mass conservation law. The air get contact with the cold surfaces and heat is transferred from the air to the water flowing inside the tubes. So there is both heat transfer and mass transfer. The description of coil model is in the following [6].

$$C_{pw}m_w(T_{ow}-T_{iw}) = C_{pa}m_a(T_{ia}-T_{oa}) = KA\frac{1}{2}(T_{ia}-T_{ow}+T_{oa}-T_{iw}) \quad (8)$$

$$T_{oas}=T_{oa}-(T_{ia}-T_{ias})(1-E_g) \quad (9)$$

Where, m is the flow rate of medium, K is the heat transfer coefficient and A is the heat transfer area.

## RESULTS AND DISCUSSTIONS

Computational simulations are carried out in toolbox Simulink of Matlab [7] and the model is regarded as transfer function of the system expressed with G(s). The response of the indoor temperature is simulated in two different control methods, PID control and Fuzzy Adaptive control combined With PID (FAPID).

**Indoor temperature response with PID control**

The theory of PID control is as follow [9]

$$\Delta u(t) = Kp\Delta e(t)+Ki\int\Delta e(t)dt+Kd\frac{d\Delta e(t)}{dt} \quad (10)$$

The temperature sensor measures the temperature in the room and compares it with the set point. Then the warp $\Delta e(t)$ is sent to the PID controller which exports $\Delta u(t)$ according to a fixed arithmetic. Kp is the proportional gain, Ki is the integral gain and Kd is the derivative gain. The model of transfer function describing the PID controlled system is shown in Figure 2.

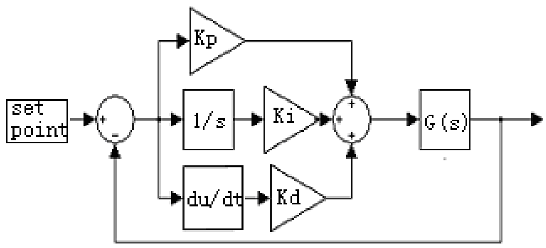


**Figure 2** A schematic diagram of PID control system

The indoor temperature response is shown in Figure 3.1. As shown, the temperature can quickly adjust to the set point with an acceptable error under the PID control after a step disturbance. But there is a problem, Kp, Ki and Kd is constant in the controller. In real system, various parameters may change with time and environment under the influence of the disturbance. To satisfy requirement, it is necessary that Kp, Ki and Kd can be adjusted automatically [8]. The control of the relative humidity is similar to the temperature and the response is shown in Figure 3.2.

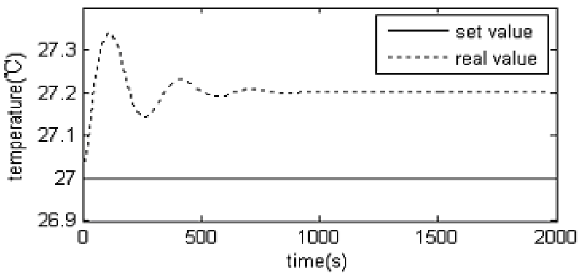


**Figure 3.1** Indoor temperature response with PID control

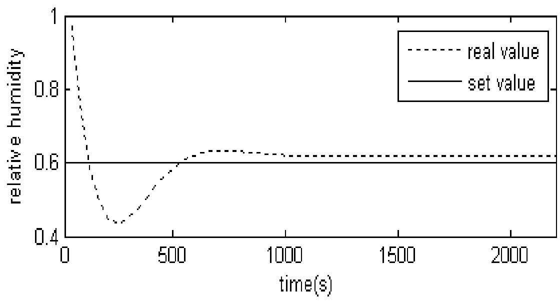


**Figure 3.2** Indoor relative humidity response with PID control

**Indoor temperature response with FA-PID control**

The FA-PID controller can adjust parameters of PID controller using fuzzy rules and fuzzy illation. The inputs of the controller are the warp 'e' and the variation ratio of the warp 'ec'. The outputs are Kp and Ki. The control system is shown in Figure 4.

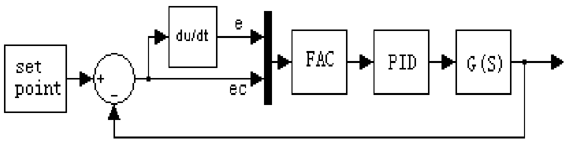


**Figure 4** A schematic diagram of FA-PID control system

The temperature sensor measures the warp 'e' between the set point and the real value and the variation ratio of the warp 'ec' and then sends them to the fuzzy controller. The controller translates the accurate values into fuzzy values and calculates the fuzzy value of Kp and Ki according the fuzzy rules and fuzzy illation.

After that, the controller exports the accurate of Kp and Ki after inverse fuzzy illation. The establishment of the fuzzy rule is based on the previous experience. For example, if e and ec are plus, Kp should be increased and Ki should be decreased. Then the adjusted Kp and Ki are sent to the PID controller so as to change the flow rate of the chilled water for the sake of keeping the indoor temperature near the set point. In this system, the area of e is (-0.5,0.5), ec (-0.02,0.02), Kp (0,0.15), Ki (0,0.015). The fuzzy aggregate of them are {NB, NM, MS, ZO, PS, PM, PB}. The corresponding subjection function is shown in Figure 5.

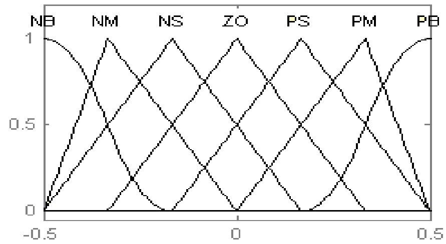


**Figure 5.1** A subjection function of e

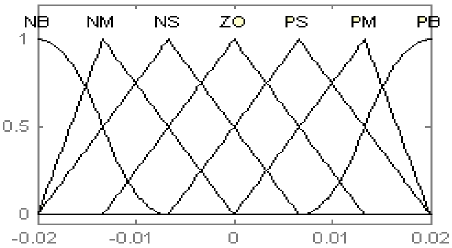


**Figure 5.2** A subjection function of ec

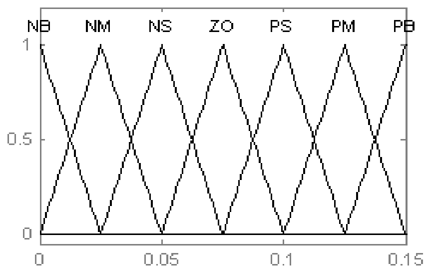


**Figure 5.3** A subjection function of Kp

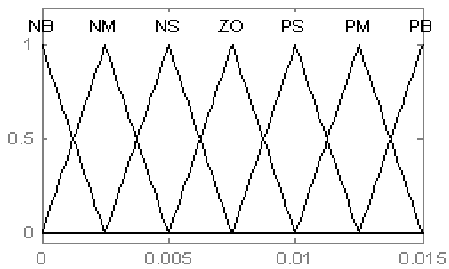


**Figure 5.4** A subjection function of Ki

The simulated indoor temperature response with FA-PID control is shown in Figure 6.1. As shown, the FA-PID temperature control is capable of rejecting disturbance effectively with capable of controlling the disturbance efficiently with less time lag and small error. Similarly, the relative humidity response with FA-PID control is shown in Figure 6.2. The FA-PID relative humidity control is also capable of rejecting disturbance effectively with capable of controlling the disturbance efficiently with less time lag and small error.

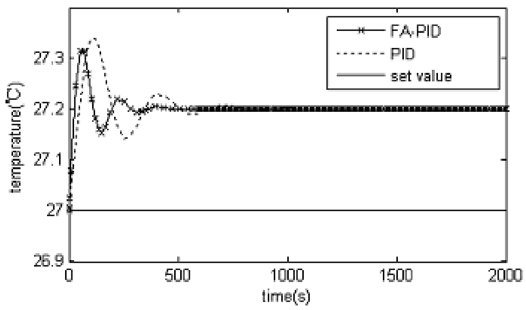


**Figure 6.1** Indoor temperature responses between PID and FA-PID control

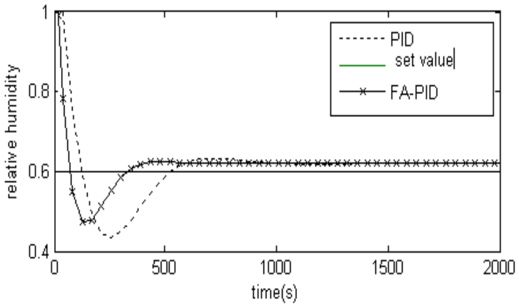


**Fig. 6.2** Indoor relative humidity responses between PID and FA-PID control

The comparison of the control quality parameters of indoor temperature and relative humidity between PID and FA-PID control is shown in Table 1. As shown, compared with the conventional PID control, the exceeding value of adjust indoor temperature is smaller and the response time is shorter with FA-PID control.

**Table 1** Control quality comparison between PID and FA-PID

| Quality Parameters | Temperature | | Relative humidity | |
|---|---|---|---|---|
| | PID Control | FA-PID Control | PID Control | FA-PID Control |
| Errors σ (%) | 1.3 | 1.2 | 28.3 | 20 |
| Time Lag tc (s) | 1100 | 600 | 1000 | 500 |

## CONCLUSIONS

Mathematical models for the components were established. The control of water flow rate is adopted. The results for the close loop responses of the system were obtained. The comparison between PID control and FA-PID control is carried. The configuration is simple and the performance is well in the conventional PID controller. But the parameters of the controller are unchangeable. When the system is non-linear, the performance will be imperfect. FA-PID controller conquers the shortage. The parameters can be adjusted according to the environment.

The results obtained from the two controllers show that the system is capable of rejecting disturbance effectively with small error and time lag under FA-PID control than under PID control.

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