White Paper

Introduction to PRAC (Pattern Recognition Adaptive Control)

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Extended Summary

The purpose of heating, ventilating and air-conditioning (HVAC) is to provide a comfortable, safe and healthy environment for building occupants. In the HVAC industry, it is common to use proportional-integral (PI) feedback control algorithms as the relatively slow actions in HVAC controls do not need the derivative (D) component.

A PI controller calculates an "error" value as the difference between a measured process variable, such as the current room temperature, and a desired setpoint, such as the desired room temperature. The controller attempts to minimize the error by adjusting the process control inputs, such as the damper opening angle of the VAV box or the opening angle of the chilled water valve. The PI parameters, i.e. the gain of the P-component and the integral time of the I-component, used in the calculation must be tuned according to the nature of the system. And this is the most difficult and time consuming task when using a PI controller. Conventionally, this tuning is carried out during the commissioning stage immediately after installation. Following this, the whole system can change due to seasonal differences, building load changes or even variations in the performance of some HVAC devices such as pumps and heat transfer pipes etc. These changes ask for a re-tuning process of the PI parameters to achieve optimal control. Manual adjustment is difficult and labour intensive, though not totally impossible. Pattern Recognition Adaptive Control (PRAC) was invented and implemented to solve this perennsal problem.

By incorporating five control blocks inside the PRAC, signals from the process, such as room temperature, are filtered to remove noise. Then, the PRAC checks whether there is a significant disturbance in terms of either the setpoint and/or the controlled process. If the disturbance is significant, the PRAC will study the pattern of the controlled process in terms of the system damping and response speed. Once this is confirmed that the actuator is not saturated and that the controller is in manual mode, the controller parameters will be adjusted by the PRAC appropriately. The PRAC has been incorporated into Johnson Controls' latest series of digital controllers. Readers who wish to learn more about the core principles of the PRAC are highly recommended to read this white paper.

1. Introduction to PID Control

The purpose of heating, ventilating and air-conditioning (HVAC) is to provide a comfortable, safe and healthy environment for building occupants. In the HVAC industry, it is common to use proportional-integral-derivative (PID) feedback control algorithms.

A PID controller calculates an "error" value as the difference between a measured process variable, such as the current room temperature, and a desired setpoint, such as the desired room temperature. The controller attempts to minimize the error by adjusting the process control inputs, such as the damper opening angle of the VAV box or the opening angle of the chilled water valve. The PID parameters, i.e. the gains, used in the calculation must be tuned according to the nature of the system. And this is the most difficult and time consuming task when using of a PID controller.

The PID controller involves three separate parameters as shown in Figure 1, namely the proportional, the integral and derivative gains, i.e. Kp, Ki and Kd respectively. The proportional gain determines the immediate reaction to the current error; the integral gain determines the reaction based on the accumulation of previous errors and that is used to remove permanent error under a steady state; the derivative gain determines the reaction based on the rate at which the error has been changing and that is used to speed up the control actions. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element.

By properly tuning the three gains in the PID controller, the controller can provide optimal control actions. The controller response can be described in terms of the speed to eliminate an error, the degree to which the controller overshoots the setpoint and the degree of system oscillation.

Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control action. HVAC systems do not usually need very speedy responses and the D mode may initiate instability due to its sensitivity to measurement noise. Therefore, PI controllers are particularly common in HVAC systems because the I mode is critical in ensuring an accurate arrival at the desirable setpoint.

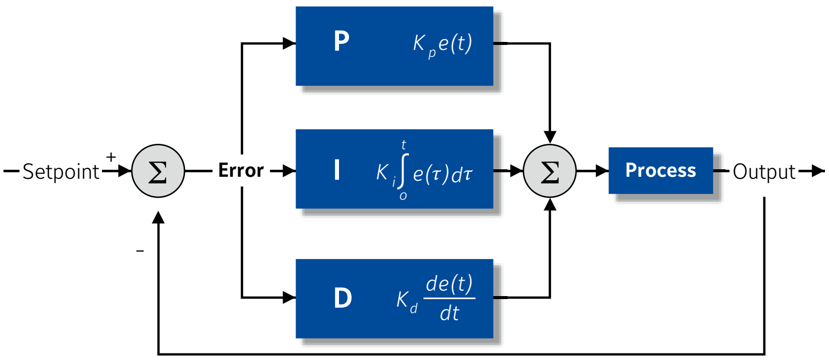

Figure: 1 A PID Controlled Process

2. Problems with existing PI Controllers

HVAC systems are not linear. For example, inside an air-duct, the air flow is not linearly proportional to the damper position, shown in Figure 2. So, when a damper starts to open, the system is very sensitive and so the gain from the controller cannot be that large. However, when the damper is almost fully open, we need increased gain from the controller as the air flow does not change much even after relatively large change in the damper position. Systems comprising HVAC components and air-conditioned environments are complicated in nature.

HVAC systems are "noisy" as parameters, such as temperature, air flow, pressure and humidity can fluctuate vigorously. HVAC systems are subject to "start-up" and setpoint changes from time to time. Moreover the performance of a HVAC system relative to the time, day and season.

Taking this into account, it is extremely difficult to tune the gains of a PI typed HVAC controller well. They may only be tuned based on experience or on a trial-and-error basis. Gains may only be optimal for a particular instant even though have been well tuned. Re-adjustments are necessary from time to time due to seasonal variations, deterioration of HVAC components or changes in the characteristics of the air-conditioned environment. Unfortunately, PI gains are only usually tuned immediately after the controller is installed. This explains why the performance of HVAC systems can deteriorate at a faster pace witeragesas components gets old and controller settings can deviate much more from the optimal point.

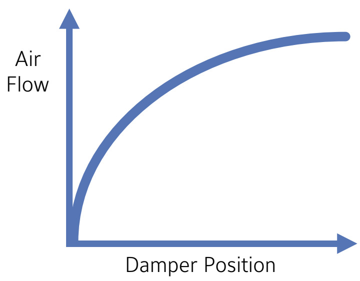

Figure: 2 Non-linearity in HVAC

3. How can this problem be fixed?

As discussed, a re-adjustment is necessary over time but manual re-adjustment is difficult, though not totally impossible. The solution is simple and obvious. Automatic re-adjustment can help fix this problem. Some algorithms can be employed to automatically re-adjust the two gains and bring the controls back to an optimal condition with respect to the current situation of the HVAC component. This is the reason why pattern recognition based re-adjustment is effective as the algorithms continuously review the current performance of both the controller and the controlled process.

PRAC (pattern recognition adaptive control) can re-adjust the two gains, i.e. the proportional gain in terms of the proportional band and the integral gain in terms of the integral time of the digital PI controller while under closed loop control. Figure 3 shows how the PRAC fits into a standard control system. The process uses the VAV box damper to air-condition the room while the pre-filter measures the room temperature and balances the signal.

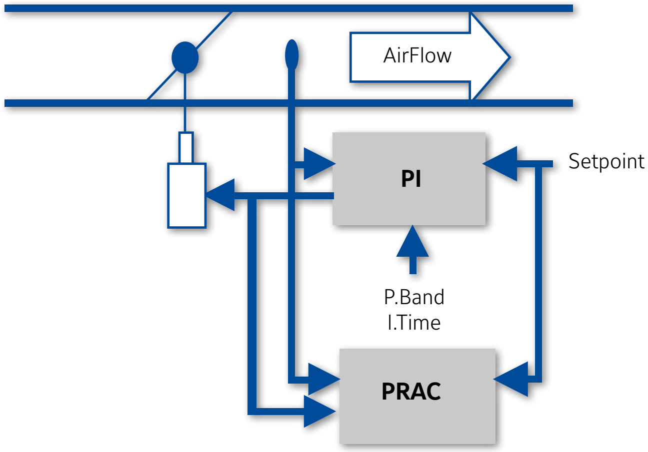

Figure 3: Block Diagram of PRAC in a Control Process

4. What is inside the PRAC?

The PRAC monitors the controlled variable, such as the room temperature, and the setpoint, such as the desirable room temperature, as well as the controller output, such as the damper or valve position angle. Figure 4 shows the five steps that take place within the PRAC.

The Analog-to-Digital converter converts the value of the controlled variable into a digital signal and that is called the process output. For example, the process is the air-conditioning serving a room and thus the room temperature is obviously the output of this process.

As discussed in section 2, the signal can be very "noisy" or fluctuating. A numerical method is employed to do some averaging to obtain a smoother signal, a smoother rate of signal change and the estimated noise. This step is performed in block 1 within the PRAC.

Then, the PRAC needs to determine whether there is any significant disturbance during the setpoint or the process. Tuning band is used to judge whether there is any significant change in the setpoint or the process output, such as the room temperature, even if there is no change in the setpoint. For example, if the new setpoint is within a range from the old setpoint minus the tuning band to the old setpoint plus the tuning band, no action is needed. This is performed in block 2 within the PRAC.

The whole system consists of the actuator, such as the damper position, and the environment, such as the room, which is subject to change from time to time due to various reasons. For example, the curve shown in Figure 2 can alter due to wear-and-tear of the damper mechanism. Another example is that the cooling load of the air-conditioned environment in terms of sensible and latent heat can vary season by season. Then, for the same amount of cool air injected into the environment, the room temperature rate of change may vary significantly. In order to arrive at an optimal control, the controller needs to understand the updated behaviour of the whole system. This can be measured by the fluctuation in process output, such as room temperature, or an action, such as a setpoint change or a load disturbance. Mathematically speaking, the behaviour is characterized by the system damping and response speed. In other words, the closed loop response of the system needs to be understood by the controller, and block 3 is responsible for this task.

The PRAC is also smart enough to avoid any unnecessary tuning under non-typical situations, especially when the controller is saturated, when the process respond erratically or when the controller is manually overridden, because further tuning in these situations would result in no better or even worse performance. The decision to halt any unreasonable updating of the controller settings is handled by block 4.

Finally, the PRAC determines new gains which are represented by the proportional band and the integral time based on the characteristics learnt in block 3. The new gains are a weighted average of the old values and the newly calculated values. The amount of weighting given to the new values depends on how significant the new pattern is compared to the old pattern and noise levels. These two gains will be used by the PI controller from that instant onward. This is done by block 5 of the PRAC. This whole process of five blocks operates repeatedly so that the PI controller can always be at its optimal settings.

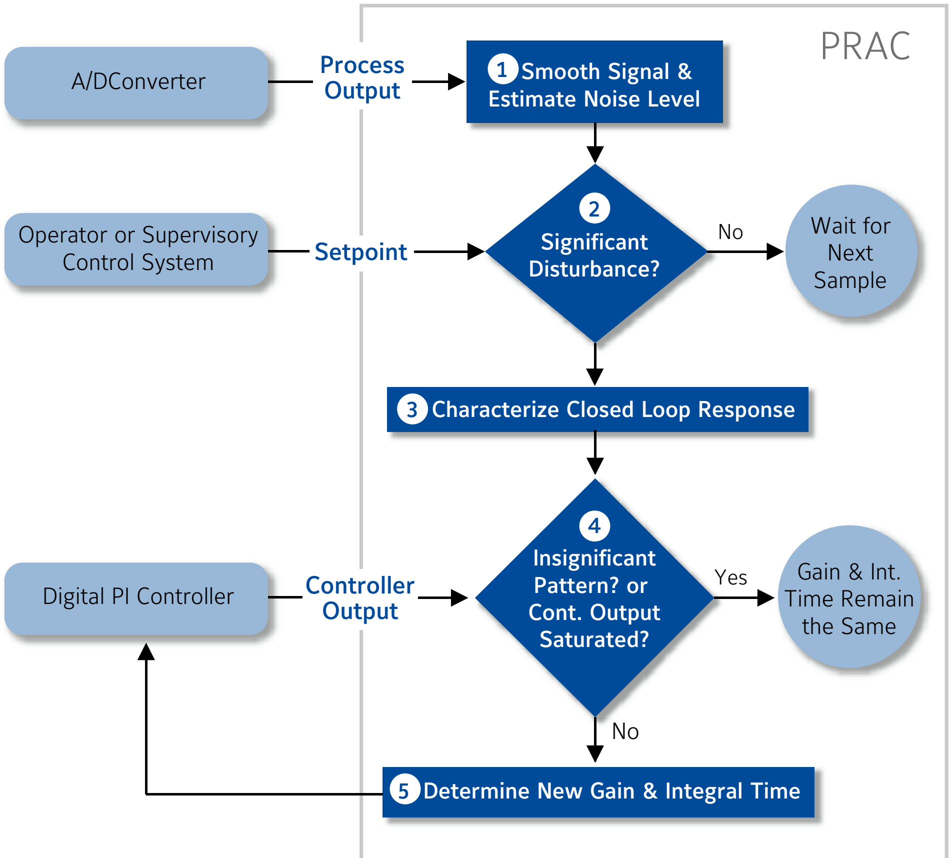

Figure 4: Flow Chart of Operation inside the PRAC

5. Key Benefits of the PRAC

The PRAC saves costs by eliminating the need to manually tune control loops from time to time. It improves comfort by ensuring robust and near-optimal performance. In addition, the PRAC can help reduce commissioning time for new control systems and eliminate the operator's time in re-tuning control loops. The life of the actuator can be increased using the PRAC as damper motor's runtime is reduced.

The PRAC can be applied to any PI control, although it was first applied in the VAV system control, i.e. the VMA 1600 Series products. The best way to understand VAV systems is to first consider them as cooling applications. As the zone temperature increases, the VAV controller opens the VAV box damper to allow more cool air to reach the space. The volume of air required to maintain a particular zone temperature setpoint is dictated by the size of space and the internal and external heat loads.

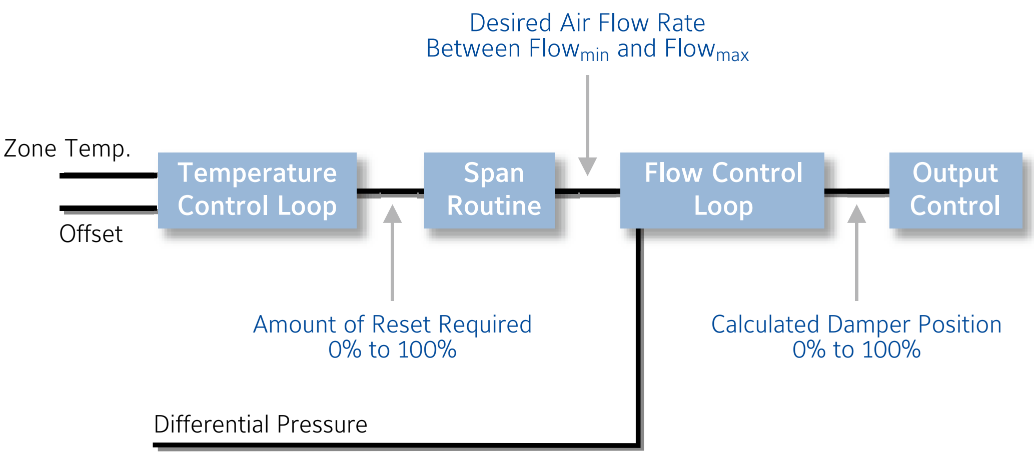

Figure 5: VAV Box Control

The VMA controller employs cascaded control loops. The zone temperature control loop, shown in Figure 5, is achieved by using PI control loops with the PRAC to tune the controller. The offset is the desirable room temperature compared to the current zone temperature. The desirable room temperature can vary upon modes of occupancy. The output of the temperature loop is used to calculate the airflow setpoint between the minimum and maximum flow settings, i.e. the desirable air flow. This is done by the Span Routine as shown in Figure 5. This airflow setpoint is used by the flow control loop that is implemented using Johnson Controls' patented Proportional-Adaptive (P-Adaptive) algorithm. The flow control loop allows the temperature control to be independent of duct static pressure. However, when two-position valves or electric heat is selected, the PRAC is disabled. The PRAC is also disabled in the event of saturation, error made and during an override situation. Furthermore, if the derivative gain is not equal to zero, for example a PID controller is used instead of a PI controller, the PRAC will not tune the controller. It is also disabled if the active PI controller does not have sufficient flow to maintain control such as in the event of saturation.

The P-Adaptive flow control algorithm uses a patented fixed gain, proportional control loop with a self-adjusting deadband whose value is related to an estimate of the noise variance. It is used for pressure independent applications by dynamically adjusting the flow deadband based on the turbulence measured on the pressure sensor. P-Adaptive does not require any tuning, which is one distinctive feature.

The VMA controller has built-in lots of advanced technological features that are beyond the scope of discussion of this white paper. Readers can easily find out more on this by checking the numerous patents associated with different components within the PRAC as shown in Figure 6. More white papers describing the technologies in depth will be available in due course.

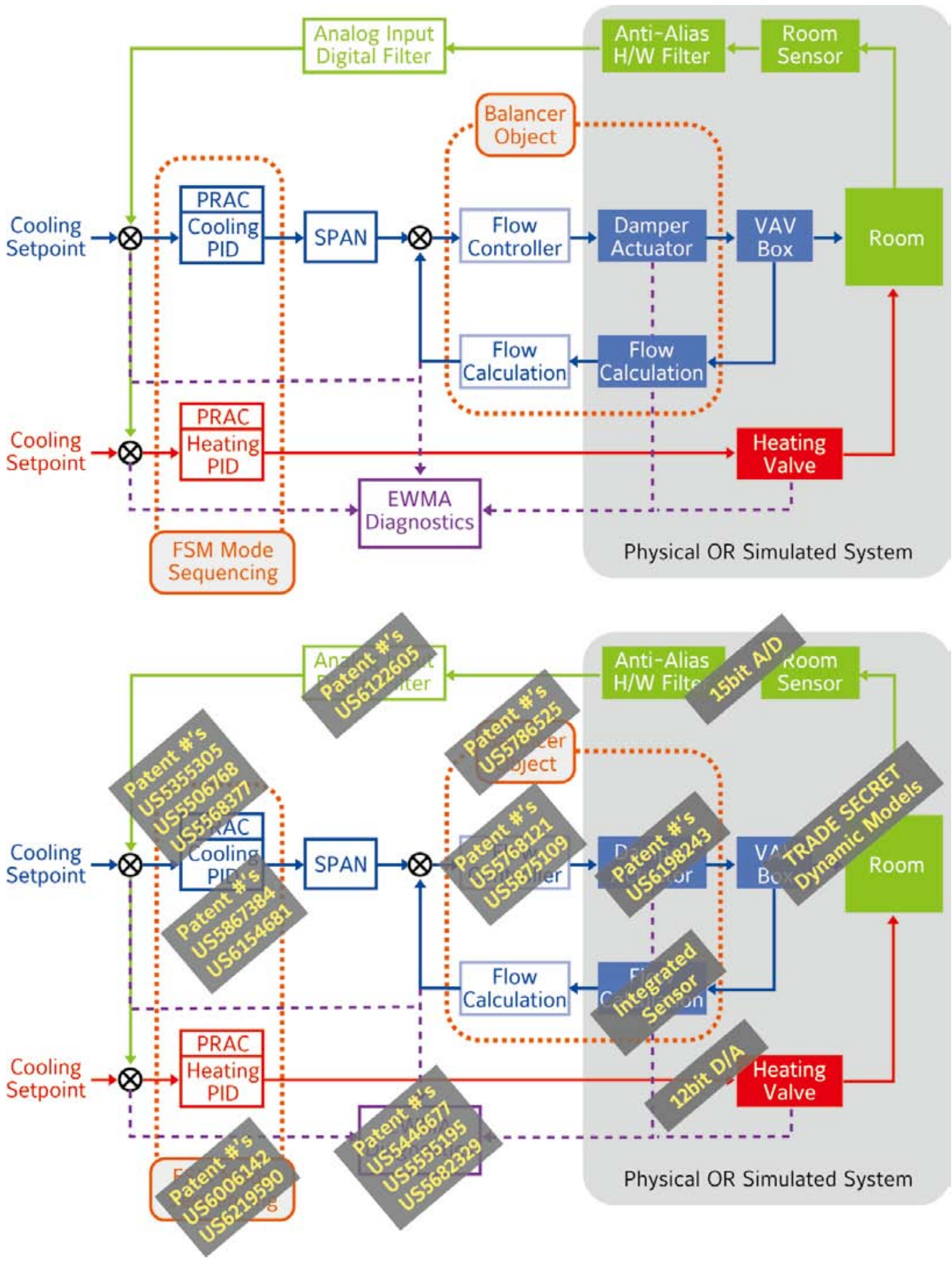

Figure 6: Patents associated with VMA Components

6. Reference

Seem J.E., "A new pattern recognition adaptive controller with application to HVAC systems", Automatica, Vol. 34, No. 8, 1998, pp. 969-982.

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