A New Approach for Temperature Control of Medical Air Insulation Blanket

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***Abstract*—To meet the technical demands of temperature control in medical air insulation blanket, a closed loop system of temperature control is put forward, in which the hardware circuit is mainly composed of temperature sensor, MCU and RS232 communication module etc. Through changing the work time of the electrically heated wire via controlling the turn-on time of the thyristor by the PWM technique and adaptive fuzzy PID technique, the air temperature from the outlet of the insulation blanket's gasbag is automatically adjusted and controlled. The whole control process is divided into two stages: the duty cycle of the electrically heated wire's work time is set to be 100% at the initial auto adjustment stage, and then is determined by a relevant control variable during the stage of adaptive fuzzy PID algorithm control when the air temperature rises up to a certain range, hence the air temperature is regulated. The MATLAB simulation based on the control method shows that the adaptive fuzzy PID algorithm control is superior to conventional PID control due to the former excellent adaptability, robustness and the steady-state accuracy.**

Keywords: Insulation blanket; Temperature control; Adaptive fuzzy PID; Matlab simulation

I. INTRODUCTION

It is an efficient way to prevent hypothermia phenomena in the process of surgery or rehabilitation by using a medical air insulation blanket [1, 2]. However, the conventional medical air insulation blanket adopts manual adjustment of the air temperature and bears some disadvantages such as hard operation, low precision and sluggish response in the control of the air temperature, etc. An intelligent medical air insulation blanket which can automatically and opportunely adjust the air temperature has been developed by the authors, by which the temperature and the flux of the air from the outlet of the gasbag of the insulation blanket are automatically adjusted and controlled in real-time to get the skin temperature of the patient in surgery stabilized at a ideal core temperature with a fluctuation of ±0.2℃ [3]. The Proportional-Integral-Derivative(PID) control method is commonly applied to control air temperature. However, it is hard to modify and regulate automatically the control parameters with the traditional PID control method when the model or the parameters of a controlled object keeps changing, so the traditional PID method is usually applied for a linear process of the controlled object with fixed mathematical model. Since the air temperature is the master-control object of the intelligent medical air insulation blanket and the control process is a time-varying, nonlinear and pure time-delay one, it is hard to establish a precise mathematical model for it with the traditional PID control method [4]. In contrast with the traditional PID control method, the adaptive fuzzy PID control method has a strong robustness and does not depend on a fixed mathematical model. The latter adjusts the proportional coefficient K_p , the integral coefficient K_i and the differential coefficient K_d by reasoning on the basis of the real-time state of the system and a proper fuzzy control strategy, and enables the controlled object to reaches a steady state quickly [5].

In this paper, the structure of the control system for the intelligent medical air insulation blanket is proposed, the adaptive fuzzy PID control method with a reasonable strategy is applied to realize the temperature control process and the whole control process is simulated and validated via the commercial software Matlab.

II. THE STRUCTURE OF THE CONTROL SYSTEM

The control system of the intelligent medical air insulation blanket is a closed-loop one which mainly consists of a single chip microcomputer AT89C52, a medical temperature sensor (DA linear PN junction temperature sensor), an A/D converter, an electrically heated wire and an air blower, etc, as shown in Figure.1.

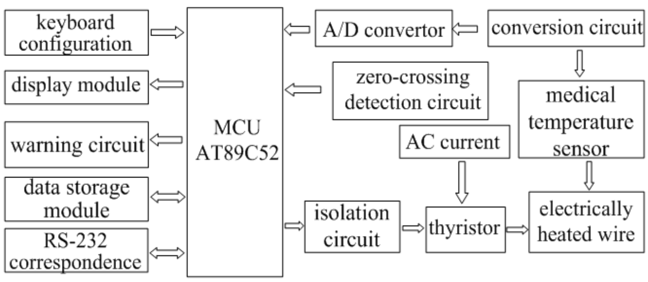

Figure 1. The structure of the control system

In the control system, the medical temperature sensor works as the response element, the thyristor is the executive element and the PWM method is used to replace the former analogue quantity controller. An analogue signals collected by the temperature sensor are transformed into digital ones and the latter are sent into the single chip microcomputer AT89C52 where the digital signals are processed and

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corresponding temperature values are eventually obtained. After the skin temperature detected in real-time is compared with the preset ideal core temperature, a control variable is obtained to adjust the air temperature through a control algorithm. The work time of the electrically heated wire is changed by controlling the turn-on time of the thyristor through the PWM technique and the adaptive fuzzy PID control method, so the air temperature from the outlet of the gasbag of the medical air insulation blanket is automatically adjusted and thus the skin temperature gradually varies to the preset ideal core temperature.

Other modules and structures of the control system are introduced as follows.

The display module which displays 0-9999 digit in two groups is composed of LED driven by the chip 74LS48. The temperature control module consists of an isolation circuit MOC3020, a thyristor BAT12 and an electrically heated wire and so on. A zero-crossing detection circuit is applied to realize bidirectional zero-crossing trigger. The data storage module is for storing the time and the temperature data gathered in real-time in case of the data loss when electricity-drop occurs. The MAX232 chip is used to perform the data correspondence between RS-232 and the PC for data display in surgery or inquiry later. A warning circuit is designed to give a alarm when the air temperature exceeds its maximum or minimum.

III. ADAPTIVE FUZZY PID CONTROL

To meet the technical demand of the temperature control in the intelligent medical air insulation blanket where the body temperature need to rise fast to a preset temperature and then remain stable, a reasonable control strategy is adopted for different temperature stages: the duty cycle of the work time of the electrically heated wire is set to be 100% at the initial adjustment stage and then adaptive fuzzy PID control is applied when the air temperature rises up to a threshold. Namely:

While error $e > e_0$, then $u=u_{max}$, the control system is at the initial auto adjustment stage;

While error $|e| \le e_0$, the control system enters into adaptive fuzzy PID control stage.

Where e is the difference value between the skin temperature detected in real-time and the preset ideal core temperature, e_0 is the temperature threshold value and u is the heat output of the electrically heated wire.

When the air temperature approaches to the preset air temperature, the work time of the electrically heated wire is changed via controlling the turn-on time in cycle by the adaptive fuzzy PID method and the skin temperature gradually reaches the preset ideal core temperature and maintains stable. Consequently, an expected elevation speed of skin temperature and dynamic performance of whole system are obtained [6, 7].

In the adaptive fuzzy PID controller the error e and its derivative or error rate e_c is taken as input data. The PID parameters including the proportional coefficient K_p, the integral coefficient K_i and the differential coefficient K_d are tuned on line based on the adaptive fuzzy PID control rule. Therefore, auto-tuning of PID parameters is realized according to the changes of the temperature error e and the error rate ec via the adaptive fuzzy PID controller.

It is important to consider the effect of the proportional coefficient K_p, the integral coefficient K_i and the differential coefficient K_d on the stability, overshoot, response speed or steady precision of the control system during the tuning process of PID parameters [8]. The adaptive fuzzy PID control method has the ability of automatically adjusting the three coefficients to achieve an optimal state.

Suppose the discourse domain of the error e and the error rate ec are [-5, 5], the fuzzy discourse domain of them is [-3, 3] and the quantizing factors of them are $K_e=K_{ec}=3/5=0.6$. The fuzzy variables e and ec are divided into 7 fuzzy sets named as {Positive Big (PB), Positive Middle (PM), Positive Small (PS), Zero (ZE), Negative Small (NS), Negative Middle (NM), Negative Big (NB)}. A fuzzy variable is obtained from the membership function of the input variables e and ec according to the maximum value method, where the membership functions are set to be triangular functions as shown in Figure 2. The linguistic variables ΔK_p、ΔK_i、ΔK_d are also divided into the 7 fuzzy sets as mentioned above and the fuzzy rules of ΔK_p、ΔK_i、ΔK_d are then designed.

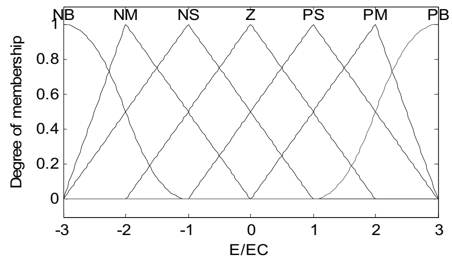

Figure 2. The membership functions of e and e_c

According to the membership functions of the fuzzy subsets and the fuzzy rules of linguistic variables ΔK_p、ΔK_i、ΔK_d, the PID parameters K_p, K_i, K_d are modified on line as follows[9]:

$$K_p = K_{p0} + \Delta K_p \; ; \; K_i = K_{i0} + \Delta K_i \; ; \; K_d = K_{d0} + \Delta K_d$$

The output $u(n)$ is calculated by the following formula:

$$u(n) = u(n-1) + K_p[(e(n) - e(n-1)) + T/T_i \; e(n) + T_d/T(e(n) - 2e(n-1) + e(n-2))$$

Where K_{p0}, K_{i0}, K_{d0} are the PID parameters initialized; T is the sampling period; $e(n)$, $e(n-1)$, $e(n-2)$ are the differences between real-time sample value and the preset values at current time, at the previous time, at the further previous time, respectively; T_i is the integrating time constant and T_d is the differentiating time constant.

IV. MATLAB SIMULATION

The model of the control system is established in Simulink environment via the Fuzzy Logic Controller provided by the commercial software Matlab and then the simulation is conducted [10]. The membership functions of the temperature error e and error rate e_c are edited and the fuzzy reasoning system based on the arithmetic of Mamdani is built by the Graphical User Interface (GUI) in the fuzzy controller, and then fuzzy rules are redacted in the regular editor [11].

A fuzzy controller AA with two inputs (e and e_c), three outputs (ΔK_p、ΔK_i、ΔK_d) and 49 rules is constructed based on the fuzzy rules of the PID parameters K_p，K_i，K_d, which is shown in Figure 3.

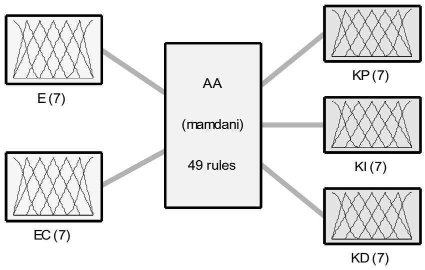

Figure 3. The structure of fuzzy controller AA

The skin temperature is adjusted through changing the air temperature from the outlet of the gasbag of the medical air insulation blanket. Since the temperature-control process is a time-varying, nonlinear and pure time delay process, it can be approximately expressed by a First Order Time Lag Procedure which is depicted by:

$$G(S) = Ke^{-\tau s}/(T_S + 1)$$

The time response constants K、T and τ are determined by measuring the response signals of the control system when unit step signal is input and then by calculating based on the Cohn-Coon formulary [12]. The time response constants K、T and τ are set to be K=1, T=60, τ=20 in order to obtained obvious simulative results. The response curve with the unit step signal as input is used to evaluate the performance of a control system in present simulation. The simulation model of adaptive fuzzy PID control method is shown in Figure 4 and its response curve is denoted by the dashed line, as shown in Figure 5. The simulation response curve of the traditional PID control is also shown in Figure 5 to have a sharp comparison between the two control methods.

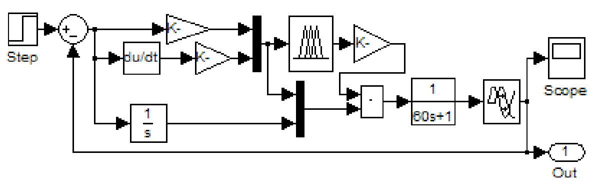

Figure 4. The simulation model of the adaptive fuzzy PID control method

Figure 5 shows that the traditional PID control method brings on an excellent steady performance, but a big overshoot, a slow respond and a distinct surge. In contrast, the adaptive fuzzy PID control method produces not only an excellent steady performance without obvious overshoot and surge, but also a quick respond, high accuracy, excellent adaptability and robustness.

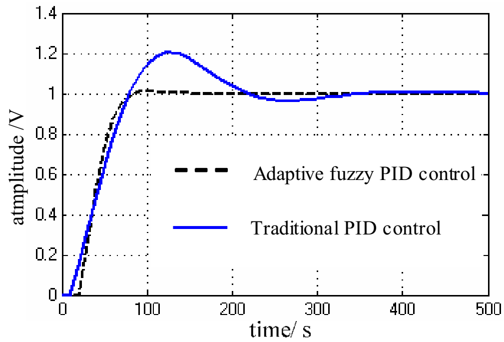

Figure 5. Response curves based on the traditional PID and adaptive fuzzy PID controls

V. CONCLUSION

The simulation results indicate that the air temperature from the outlet of the gasbag of the intelligent medical air insulation blanket is risen rapidly and stabilized nearby the preset temperature value by applying a proper control strategy at different temperature stages based on the adaptive fuzzy PID control method. Moreover, the whole control process bears a good adaptability and robustness without complex manual tuning. This well meets the temperature control requirements of intelligent medical air insulation blanket such as automation, speediness, precision and the stability.

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