Design of high-precision micro-automatic control system based on Segmentation driven and closed-loop control

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Abstract. The high-precision micro-infusion automatic control system is an automatic infusion system that replaces manual infusion which solves the risk that the traditional infusion volume and speed cannot be controlled. By analyzing the system composition and configuration, it is determined that the system actuator belongs to the field of multi-body mechanics. After analysis of the system mechanics model, it is ensured that the mechanical performance of the designed system's actuator meets the requirements. At the same time, the motor control method of subdivision drive and closed-loop control used in the design is described in detail, and the dynamic characteristics of the system are simulated and analyzed. High-precision and reliability control ensure that the medicine can enter the patient's body uniformly, accurately and safely, and meet the design requirements.

1. Introduction
In clinical medicine, although infusion is widely used, it is a high-risk treatment. In the infusion therapy, the clinic must be equipped with an appropriate infusion rate and dose according to the different drugs and patient conditions [1]. If the infusion is too fast, it may lead to toxic reactions, and more severely, it may lead to edema and even heart failure in the patient. If the infusion rate is too slow, it may result in insufficient medicine or prolong the infusion time, which not only affects the treatment, but also adds unnecessary burden to patients and nursing work [2-3]. The use of automatic infusion system is an effective measure to solve the above problems. At present, the automatic infusion systems commonly used in China are still relatively backward, with low accuracy, and manual monitoring is the main method [4-5]. This method has a greater risk of infusion. Inaccurate control of the infusion speed, dose, temperature, etc. often directly affects the infusion [6]. The treatment effect is even life-threatening.

The high-precision micro-automatic control system designed in this paper is a system that can accurately control the number of infusion drops or the infusion flow rate, ensure that the drug can be evenly distributed in speed, and that the amount of medicine can accurately and safely enter the patient's body to play a role. The efficiency, precision and flexibility of medicine operation improve the treatment effect.

2. System composition and configuration
The high-precision micro-automatic control system can be divided into different equipment such as infusion pumps, syringe pumps, nutrition pumps, target-controlled pumps, and infusion instruments according to the specific medical application direction[7-8]. However, the principle of the device is basically the same, all of which are to control the speed and accuracy of drug delivery. As shown in
Figure 1, the main components of a typical high-precision micro-control system can be divided into an execution module, a host, a controller, and a display module according to their functions.

2.1 Execution module
The execution module includes a reduction motor and an actuator, which directly act on the consumables of the pipeline. The main function is to convert the rotary motion output by the motor into a linear motion that pushes the drug piston in the pipeline through the actuator to accurately inject the drug into the patient.

2.2 Controller module
The controller module controls the function realization of the entire automatic infusion device. It takes the ARM processor as the core and expands the function module to realize the entire infusion function. At the same time, it realizes the accurate calculation of the output drug dose and the real-time monitoring of the injection pressure. In order to ensure product performance and supply cycle, the mainstream processors in the market are selected.

2.3 Display module
The display shows the high-precision micro-automatic control system operating status information, including drug dose injection information display, injection pressure information real-time display, and injection mode display. At the same time, touch-screen-based input of treatment-related operations can be realized.

3. Mechanical analysis of multibody systems
The high-precision micro-automatic control system actuator belongs to the field of multi-body mechanics, and the system mechanics model needs to be analyzed to ensure that the mechanical performance of the system actuator meets the requirements [9]. Since the mechanism for pushing the liquid to flow forward is a rigid body, and the fluid is a flexible body, to analyze the mechanical properties of the entire system, it is required to apply a pressure on the end of the rigid body, that is, the beginning of the flexible body [10]. First, a liquid flow model in a drug tube is established. The model discussed in this system can be simplified as shown in Figure 2.
The capacity of a single cartridge is 1.7 ml, calculated at the maximum speed, the screw piston advance speed is 9 mm/s, the general injection speed is 1 mm/s, and the minimum is almost stationary, so it can be considered that the fluid incompressible fluid flows constantly. First consider the Reynolds number \( \text{Re} \):

\[
\text{Re} = \frac{\rho v D}{\mu}
\]

(1)

It is obtained that \( \text{Re} = 59.7 < 2300 \), and it can be known that the liquid medicine flow in the syringe is laminar.

Suppose the pressure, speed and cross-sectional area of the liquid in the syringe are \( P_1, v_1, A_1 \), and the pressure, speed, and cross-sectional area of the liquid in the extension tube are \( P_2, v_2, A_2 \), respectively.

Bernoulli equation:

\[
P_1 + z_1 + \frac{v_1^2}{2g} = P_2 + z_2 + \frac{v_2^2}{2g}
\]

(2)

Combine the continuity equation:

\[
v_1 A_1 = v_2 A_2
\]

(3)

inferred:

\[
P_1 = P_2 + 1/2\rho v_1^2 \left( \frac{A_1}{A_2} \right)^2 - 1
\]

(4)

\[
P_1 = P_2 + 1/2\rho v_1^2 \left( \frac{A_1}{A_2} \right)^2 - 1
\]

(5)

We get \( P_1 = P_3 + 20811.8 \). When the needle tube is blocked, consider the medium threshold (60kpa) to get \( P_1 = 80.8 \text{kpa} \), and then get the resistance received at the end of the transmission system \( \Delta F = \Delta p \cdot A_1 = 2.85 \text{N} \). Based on the above analysis basis, finite element analysis is performed on the mechanical performance of the system actuator. The results of stress-strain analysis are shown in Figures 3 and Figures 4.

It can be concluded that the maximum rotation deformation is 0.129 mm, and the distance converted to the forward movement of the cartridge is 0.0068 mm, which can be ignored, so the system actuator meets the needs.
4. Subdivision drive and closed-loop control
The core of the high-precision micro-automatic control system is the precise control of the motor, which requires precise control on the two parameters of infusion rate and infusion dose [11]. In order to achieve high-precision and reliability control of the system, the control system uses a multi-closed cascade composite control scheme, which combines a current loop, a speed loop, and a digital position loop. The control structure diagram is shown in Figure 5.

![Figure 5. Schematic diagram of the structure of the closed-loop control system](image)

The current loop control and speed loop control are completed by the driver, the digital position loop control is completed by the core controller, and the position-type PID algorithm of composite control is used. The principle block diagram of the algorithm is shown in Figure 6.

![Figure 6. Principle block diagram of positional PID control algorithm](image)

The DC motor uses dual closed-loop control of speed and current, and needs to obtain the motor rotor speed and position information in real time [12]. In this paper, an incremental photoelectric encoder is selected and installed on the motor shaft. The pulse signal sent by the photoelectric encoder is sent to the ARM control board to obtain the motor speed and rotor rotation angle. The real-time measured speed and the given speed are passed through the speed together. The modulation link obtains the current given value of the current modulation link. In addition, the ARM control board measures the actual phase current of the motor through the current detection module, and the detected current value is sent to the controller and the controller after being processed by the A/D conversion part. The current setting value of the adjustment link is modulated to generate PWM signals with different pulse duty ratios. The generated PWM signals are sent to each power switch tube of the drive circuit to drive the motor after commutation control and PWM modulation. As shown in Figure 7, the drive circuit module includes two parts: motor drive and drive protection. If an abnormal current, voltage, W, or abnormal motor operation occurs during the motor operation, the drive protection part will report the abnormal situation to the control system, and it protects until the controller sends a normal working signal.
In order to achieve high accuracy and reliability control of the infusion rate, the target position is always set during the position control on the premise of ensuring the position accuracy. The position control method is used to subdivide the position control into N target positions to achieve precise control. In this way, we can accurately control the injection speed. The schematic diagram of the position control subdivision method is shown in Figure 8.

5. Simulation

In order to verify whether the point-to-point tracking accuracy meets the requirements under the condition that the speed of the automatic control system is controllable during the injection of the medicinal solution, the dynamic characteristics of the system are analyzed, and the result of the sinusoidal signal response is shown in Figure 9 and Figure 10.
It can be seen that the position error is within about 0.2mm, and according to the system accuracy requirement of 0.1ml, the corresponding position is moved by about 2.5mm, indicating that the position error is small and meets the requirements.

6. Conclusion
In this paper, by analyzing the composition and configuration of the high-precision micro-automatic control system, it is determined that the system actuator belongs to the field of multibody mechanics. After analysis of the system mechanical model, it is ensured that the mechanical performance of the designed system's actuator meets the requirements. At the same time, the motor control method of subdivision drive and closed-loop control used in the design is described in detail, and the dynamic characteristics of the system are simulated and analyzed. The accurate and reliable control ensures that the medicine can enter the patient's body evenly, accurately and safely, and meets the design requirements.

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