Research on injection speed control algorithm of oral anesthesia booster based on dynamic pressure detection

Jingdong Li
Jiangsu Automation Research Institute, Lianyungang, Jiangsu Province, 222061, China
medical_716@163.com

Abstract. Oral anesthesia booster is an automatic injection system that replaces manual precise injection and solves the problem of abnormal pain caused by traditional oral anesthesia injection. Through the analysis of the system composition and model, it is determined that the pressure at the output end of the motor collected by the system in real time mainly reflects the load torque of the motor, so as to obtain the dynamic pressure detection method. According to the results of comparison with the high and low pressure thresholds, the oral anesthesia booster is controlled to select an appropriate injection speed mode. In addition, the pressure detection process is described, and the dynamic characteristics of the system are simulated and analyzed, which proves that the speed response of the system is timely after the dynamic pressure changes. The system can automatically alarm for obstruction or leakage according to the monitoring results, remind the doctor to correct the pressure and needle insertion position applied to the handle, so as to maintain the most rational needle insertion position and pressure, reduce the patient's pain, and improve the comfort of treatment.

1. Introduction
Infusion is the most common and treatment in the medical process and it plays a very important role in the medical process. With the rapid development of medical technology today, replacing traditional infusion methods with infusion equipment is an important development and breakthrough in medical technology [1]. The high-precision micro-infusion device can pump the liquid medicine into the patient's body accurately, minutely, uniformly, and continuously. The operation is convenient, timed, and quantitative. The concentration and speed of the drug can be adjusted at any time according to the needs of the disease, so that the drug can maintain effective blood in the body. Concentration is safer than traditional manual injection, and can monitor abnormal conditions such as blockage during infusion in real time, and provide an alarm function. At the same time, it can reduce the workload of medical staff and improve work efficiency.

Oral anesthesia refers to the local injection of anesthetics in the oral cavity to eliminate the pain of the patient. It is commonly used in oral and maxillofacial surgery, endodontic treatment, peripheral compression treatment, dental implant surgery and other occasions [2-3]. The traditional oral anesthesia method uses disposable syringes, and the patient is prone to fear, and the doctor is inconvenient to operate the bolus manually. If the bolus time is long, it is easy to fatigue. The oral anesthesia booster is a high-precision infusion device that replaces the physician to inject oral anesthetics. The foot control injection method can free the doctor's hands and make oral local anesthesia easier [4].
The injection speed of oral anesthesia booster is generally divided into two modes: fast and slow. According to the range of action of different anesthetics, the appropriate injection speed should be selected to achieve the desired anesthetic effect. The existing injection speed control method is that the doctor decides which injection speed mode to use for different anesthesia injection needle positions based on experience, and then applies corresponding force on the foot switch to achieve the purpose of controlling the injection speed. This method relies heavily on the doctor’s experience. Doctors often make incorrect injection methods due to misjudgment or operational errors. The injection speed into the patient’s oral tissue is too high, causing abnormal pain in the patient [5-6].

Aiming at the above problems, this paper adopts an oral anesthesia booster injection speed control algorithm based on dynamic pressure detection [7]. By detecting the real-time pressure changes of the oral anesthesia booster, and according to the comparison results with the high and low pressure thresholds, the oral anesthesia assists the pusher to automatically control the injection speed mode.

2. System introduction and model
Oral anesthesia booster is positioned high-end, the main features and functions are: quantitative and accurate injection, real-time screen display of injected volume, foot control start and stop, automatic suction function, injection mode selection, resistance detection during injection and screen display, etc [8]. The outline and composition structure diagram is shown in Figure 1, which mainly includes the display module, the transmission system, the control system and the shell. The display module contains display and touch components, which are mainly used to display information such as the injected volume, injection speed, resistance and the response of the action switch during the injection process; the transmission system includes motors, reducers, couplings, screw rods, and ejector rods. , Is mainly used to provide the power to push the anesthetic piston in the cartridge to move upward; the control system includes circuit board, motor driver, power supply, start pedal, etc.; the shell includes upper and lower shells, pipeline fixing seats and internal fixing parts.

![Figure 1 the composition of the oral anesthesia booster system](image)

The actuator module contains a geared motor and an actuator, which directly act on the pipeline consumables. 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 forward through the actuator, thereby accurately injecting the medicine into the patient. In order to ensure the safety of the infusion process, the system
collects the pressure at the motor outlet in real time, and the outlet pressure mainly reflects the load torque of the motor. According to the empirical formula of DC motor starting torque [9]:

\[ T_s = 9.08K_eI_k \]  

(1)

\( T_s \): Starting torque;

\( K_eI_k \): The output power of the motor in the critical braking state at one revolution per minute;

9.08 is the empirical coefficient, which is derived from the torque-power conversion constant 9.55. Although this formula is used to obtain the starting torque of the DC motor, when the magnetic circuit is not saturated, the output torque of the DC motor is linear with the current Relation; you can use it to find the load torque under any load of the DC motor [10]:

\[ K_e = \frac{U - IR_u}{n} \]  

(2)

\( R_u \): Armature resistance;

\( n \): Motor speed;

Among them, the armature resistance is measured by the dynamic test method, that is, under the same magnetic field conditions, three sets of data are measured \( U_1, I_1, n_1 \); \( U_2, I_2, n_2 \); \( U_3, I_3 \), \( n_3 \). Among them, the armature resistance is measured by the dynamic test method, that is, under the same magnetic field conditions, three sets of data are measured. The three groups are no-load measurement at one point, and then any load is added to measure two points. According to the principle of equal back-EMF coefficients, three sets of equations are listed. Find three \( R_u \) and take the average, the equation is:

\[ \frac{U_1 - I_1R_u}{n_1} = \frac{U_2 - I_2R_u}{n_2} \]  

(3)

After finding the torque, use the following formula:

\[ F = \frac{T_s}{d} \]  

(4)

\( d \) is the radius of the motor output shaft.

Thus, the pressure at the output end of the motor can be detected in real time.

3. Injection speed control algorithm

In this paper, a piezoresistive pressure sensor is arranged at the end of the motor output shaft of the oral anesthesia booster to detect the dynamic pressure of the injection site, and according to the comparison results with the high and low pressure thresholds, the oral anesthesia booster is controlled to adopt an appropriate injection speed mode. Its control algorithm flow chart is shown as in Fig. 2.
According to the dynamic pressure data detected by the pressure sensor, the oral anesthesia booster uses the following methods to determine which injection speed mode to use:

Sampling the adjacent pressure values, the high and low pressure thresholds are $P_v$, record the difference between the $i+1$ group pressure value $P_{i+1}$ and the $i$ group pressure value $P_i$ as $\Delta i$, $i=1,2,3,...$, and based on the comparison between $\Delta i$ and 0, the following judgments are made:

1. When $\Delta i = P_{i+1} - P_i > 0$, further compare the difference between $P_i$ and $P_v$. If $P_i - P_v \geq 0$, the oral anesthesia booster adopts the slow injection mode; if $P_i - P_v < 0$, then compare the difference between $P_{i+1}$ and $P_v$. If $P_{i+1} - P_v \geq 0$, the oral anesthesia booster adopts the slow injection mode; if $P_{i+1} - P_v < 0$, the current injection speed will remain unchanged.

2. When $\Delta i = P_{i+1} - P_i < 0$, further compare the difference between $P_{i+1}$ and $P_v$. If $P_{i+1} - P_v < 0$, the oral anesthesia booster adopts rapid injection mode; if $P_{i+1} - P_v \geq 0$, then compare the difference between $P_i$ and $P_v$. If $P_i - P_v \leq 0$, the oral anesthesia booster adopts rapid injection mode; if $P_i - P_v > 0$, maintain the current injection speed unchanged.

3. When $\Delta i = P_{i+1} - P_i = 0$, keep the current injection speed unchanged.

In addition, the system can also use a linear current feedback mechanism to monitor the current of the motor, and determine the motor load according to the relationship between the motor load and the current, thereby converting it into the real-time pressure of the infusion process. The monitored pressure is displayed on the screen for the doctor's reference; an alarm will be given when the pressure exceeds the preset value. The specific control is shown in Figure 3.
4. Simulation
In order to verify whether the speed response of the oral anesthesia booster is timely after the dynamic pressure change is detected in real time [11], the dynamic characteristics of the system are analyzed by simulating the point-to-point tracking accuracy of the speed ramp signal, and the slope signal response result is obtained as shown in Figure 4 and Figure 5.

![Ramp signal response curve](image1)

![Partial enlarged view](image2)

Figure 4: Ramp signal response curve
Figure 5: Partial enlarged view

It can be seen that the position error is within 0.02mm, and the position error is very small, which meets the system requirements.

5. Conclusion
This paper analyzes the composition and model of the oral anesthesia booster system and determines that the pressure at the output end of the motor collected by the system in real time mainly reflects the load torque of the motor, so as to obtain the dynamic pressure detection method. According to the results of comparison with the high and low pressure thresholds, the oral anesthesia booster is controlled to adopt an appropriate injection speed mode. At the same time, the pressure detection process is explained, and the dynamic characteristics of the system are simulated and analyzed. It is
concluded that the point-to-point tracking accuracy of the system meets the requirements, which proves that the speed response of the system is timely after the dynamic pressure changes, and the system can block or infiltrate according to the monitoring results. Leakage automatic alarm reminds the doctor to correct the pressure applied to the handle and the needle insertion position, so as to maintain the most rational needle insertion position and pressure, reduce the patient's pain and improve the comfort of treatment.

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