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Research on the Design and Application of Infusion Pump Testing System

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Abstract

The design and research of infusion pump detection systems is crucial because infusion pumps are precise, consistent, continuous pumps that are pumped into the tool's body based on the actual drug concentration and pumping speed adjustment. This helps to improve the quality of treatment provided by essential medical equipment. This paper discusses the infusion pump detection system in detail, clarifies the infusion pump's structure and working principle, elaborates on the hardware and software design program of the detection system, and uses performance testing to confirm the system's accuracy and dependability. This paper offers a theoretical foundation and practical recommendations for the further optimization and broad implementation of an infusion pump detection system, which is crucial for guaranteeing infusion safety and enhancing the standard of medical care.

Keywords

Infusion pump, Inspection Systems, Medical equipment.

1. INTRODUCTION

The therapeutic efficacy and patient safety are strongly correlated with the accuracy and dependability of infusion pumps, which are essential pieces of equipment in clinical therapy in healthcare institutions [1]. In the medical process, infusion pumps must accurately control the flow rate and volume of infusion to ensure that the drug can be delivered to the patient at a stable rate to achieve the expected therapeutic effect [2]. Therefore, it is necessary to design a series of efficient and accurate testing systems for infusion pumps. In this paper, we discuss the design principle, realization method of infusion pump testing system and its application in actual medical scenarios to provide theoretical support and practical reference for the design and application research of infusion pump testing system, so as to ensure the safety and effectiveness of infusion pump in clinical use and further improve the quality of medical services.

2. DESIGN OF INFUSION PUMP TESTING SYSTEM

2.1. Hardware design

In this paper, a number of key parameters of the infusion pump are accurately detected, including instantaneous flow rate, average flow rate, pipeline obstruction pressure and temperature and other core indicators, the detection module of each indicator adopts a mutually independent architectural design, so that the system can synchronize the measurement of different parameters at the same time, and there is a close internal logic correlation between these independent modules, which do not operate in isolation but are related to each other and corrected each other, greatly improving the detection efficiency. These

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independent testing modules are closely related to each other, not in isolation, but related to each other and correct each other, which greatly improves the testing efficiency[3].

2.2. Infusion pump testing system module design

The infusion pump detection system includes seven modules: communication protocol, parameter initialization, data processing, image display, data analysis and data storage and reading. The communication protocol module utilizes the serial interface for data communication, solves the data exchange function, and completes the control of the lower computer and data acquisition; initialization settings are made for the collection period of flow, pressure, temperature and the time interval of individual data measurement; according to the collected data indexes of flow, pressure, temperature and so on, data processing function modules such as data analysis function are set up, and data processing function modules such as measurement scaling, interpolation calculation, data statistical analysis, data display transformation and other data processing function modules. When carrying out data processing, it is necessary to consider the influence of temperature on the signals of flow rate and pressure in order to carry out the correction calculation and get the correction of the measurement data block[4]; according to the data visualization, carry out the data and image display processing on the flow rate and pressure; set up the holding and reading function for the data obtained from the measurement; and according to the measurement results, carry out the analysis and calculation of the data error.

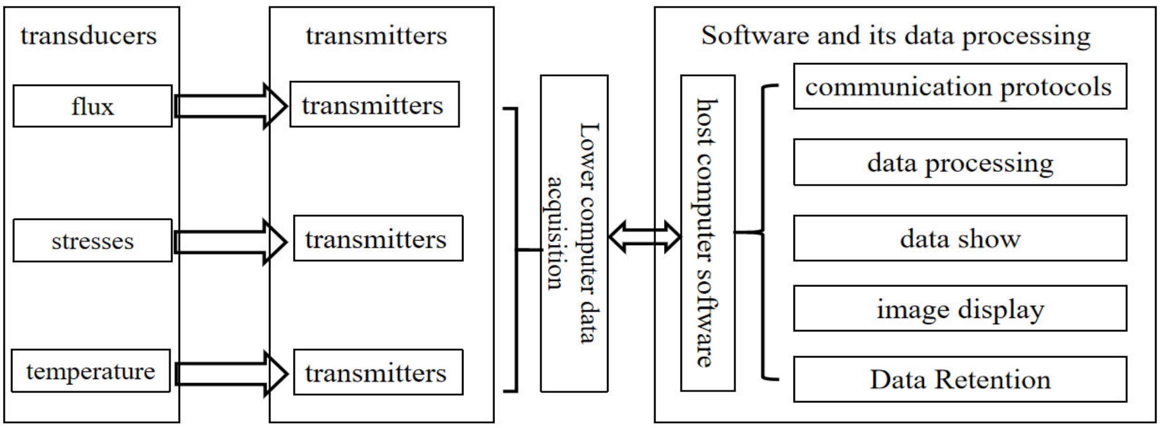

Figure 1. Modular integration of signals

3. SOFTWARE REALIZATION OF INFUSION PUMP TESTING SYSTEM

3.1. Detection system lower computer software design

3.1.1 Programming languages

This paper selects C language as the programming language, it has both high-level language features and can be easily connected with assembly language, is rich in structured computer language, support for sub-regional design, code simplicity, readability, execution efficiency and good portability, very suitable for embedded systems development. Its modular characteristics are conducive to reading and maintenance, most microcontrollers support C compiler, program portability, can improve code reuse, reduce development time. At the same time, the STM32 microcontroller supports C programming and provides developers with corresponding firmware libraries to facilitate user programming.

3.1.2 System integration development environment

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In this thesis, Keil MDK is chosen as the development tool for software design, based on the ARM embedded development environment for the STM32 development platform.Keil MDK is characterized by ease of use, ease of entry, and compact code, and provides a complete development solution including a C compiler, macro assembler, linker, library management, and simulation debugger, which can be used to develop the software through an integrated development environment (uvision) combines these features. Its interface is friendly, easy to learn and use, powerful in debugging programs and software simulation, with a full-featured source code editor, a rich library of devices, integrated source-level simulation and debugger, as well as complete development tools and help documentation and other features.

3..1.3 General software architecture

The software design of the lower computer of the system adopts the modular programming idea, and the software part mainly includes clock and reset setting, ADC register setting, watchdog, A/D conversion program, interrupt controller (NVIC) setting and interrupt program, Direct Memory Access (DMA) channel setting, serial port communication (UART) program, timer program, and each parameter processing program, etc. The overall architecture of the software is clear and the modules are clearly divided into work to realize the system functions. Each parameter processing program is based on the STM32 firmware library, the overall architecture of the software is clear, and each module has a clear division of labor and works together to realize the system functions.

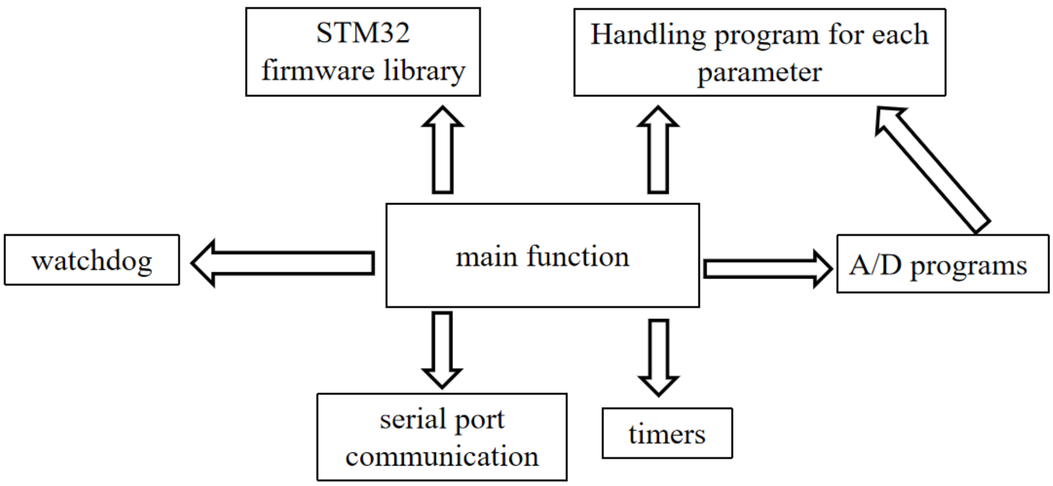

Figure 2. Lower computer software system architecture

3.2. Detection system upper computer software design

3.2.1 Communication interface design and data protocols

(1) Design of communication interface

The upper computer and the lower computer communicate through the serial port, using overlapping operations combined with multi-threaded processing, VC++, MFC programming environment, the use of controls or API functions to achieve serial communication, integrated data acquisition, display and multi-threaded processing technology.

The communication interface design includes four steps: open serial port, serial port setup, serial port read/write and serial port close, which are realized by API functions such as CREATEFILE, GETCOMMSTATE and CloseHandle, etc. Each function has corresponding parameter settings to ensure the normal serial port communication.

(2) Data protocols

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The data between the upper computer and the lower computer is transmitted in the form of "frame", and the frame structure consists of frame header, data area, and frame tail, which contains information such as frame header symbol, length, repeated frame header, communication address, command number, command parameter, checksum, and frame tail symbol, etc. The parameters of the communication protocol are clearly specified, and the data format changes according to the command words and parameters. The commands in the data protocol include start test command, stop test command and data return command, and the return data format contains information such as conductivity, temperature, venous pressure, arterial pressure, dialysate pressure, pH, dialysate flow rate and so on.

3.2.2 Correction and calculation of physical parameters

Physical parameters of the correction and calculation using a unified model to the flow, pressure and temperature, for example, the calculation method is as follows:

(1) Flow: turbine flowmeter sensor transmitter output signal processing formula is:

$$f = f(c)\, F_\alpha F_T$$

f is the flow rate, c is the count, $f(c)$ is the theoretical value of the flow rate corresponding to the count, F_α is the temperature expansion correction factor, and F_T is the scale factor.

(2) Pressure: Pressure sensor transmission signal processing formula is

$$P = \frac{P_{i+1} - P_i}{V_{i+1} - V_i}(V - V_i)\, F_p$$

P is the pressure, V is the acquisition voltage, V_i and V_{i+1} correspond to the voltage output values at pressure P_i and P_{i+1} scales, F_p is the calibration factor, which is obtained by a linear fitting algorithm.

(3) Temperature

$$T = \frac{T_{i+1} - T_i \mathrm{T}}{V_{i+1} - V_i}(V - V_i)\, F_T$$

T is the temperature, V is the acquisition voltage, V_i and V_{i+1} correspond to the voltage output values at temperatures T_i and T_{i+1} scales, and is the calibration factor, F_T which is obtained by a linear fitting algorithm.

3.2.3 Multi-threaded design for data acquisition and data processing

(1) Event-driven triggered data collection

Using event driver for data acquisition, the basic process is to create events and send data commands to the serial port, the serial port sends the commands to the lower computer, the lower computer collects the data and then transmits it to the serial port, the formation of the event triggers the multi-threaded reading and processing of the data, and the cycle of this process completes the data acquisition.

(2) Multi-threaded realization of data collection and processing in the background loop

Multi-threaded processing includes the steps of defining multiple threads, starting threads, collecting data, waiting for events, receiving serial port data to trigger events, reading data processing, and closing threads, etc. The multi-threading technology realizes high efficiency of data collection and processing, avoids program thread blockage, and improves system response speed.

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4. PERFORMANCE TESTING AND ANALYSIS OF INFUSION PUMP TESTING SYSTEM

4.1. Test methods and standards

The infusion pump testing system needs to comply with GB 9706. 27 - 2005 “Medical Electrical Equipment Part 2-24: Infusion Pumps and Infusion Controllers Safety Specific Requirements”[5] and JJF1259-2018 “Calibration Specification for Medical Syringe Pumps and Infusion Pumps”[6]. The test procedure includes measuring the basic flow error, blockage alarm and other key indicators. When performing the basic flow rate error test, a fixed proportion of the maximum set value is first selected as the starting reference for calibration, and multiple calibration nodes are set over the entire range of flow rate. The actual flow rates at these nodes are measured one by one using sensors, and the deviation value between the actual flow rate and the preset flow rate at each calibration point is calculated accordingly. In blockage alarm error control, an absolute error and a relative error are calculated by setting a blockage state of an infusion pump or syringe, recording the blockage pressure measured by the sensor, and comparing it with a blockage alarm threshold set by the device.

4.2. Analysis of test results

The error requirements within different ranges are different, 5-19.9mL/h error⩽±2%, 20-200mL/h error⩽±1%, 201-1000mL/h error⩽±2%. The measurement error of t he detection system in each range meets or is better than the standard requirements, indicating that the system flow measurement accuracy is high. In terms of blocking pr essure measurement, the measurement range is 0-200kPa, the error is less than ±1%, and the test results show that the system can accurately measure the blocking pr essure to provide protection for the safe operation of the infusion pump. Comprehensi ve flow test results test the repeatability and stability of the detection system to impr ove the reliability of the infusion pump test results.

5. CONCLUSION

Ensuring the accuracy and stability of the use of medical infusion pumps is crucial to the safety of patients' lives, so the in-depth study of the quality detection system of infusion pumps is of great significance. This paper provides an in-depth discussion on the design and application of the infusion pump detection system, clarifies the working principle and structure type of the infusion pump, introduces the hardware and software design architecture of the detection system, and verifies the performance of the system in terms of accuracy and reliability through a series of performance tests. In practical application, the detection system has played an important role in medical institutions, effectively guaranteeing medical quality and safety, and providing theoretical basis and practical experience for further optimization and promotion of the infusion pump detection system.

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