

Design and Implementation of a Household Massager Based on STM32

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Abstract: With the rapid development of society and the continuous improvement of living standards, people's demand for health and comfort is increasing. Household massage instruments have attracted wide attention for their convenience and economy. Aiming at the design and implementation of a household massager, this paper uses the STM32F103C8T6 microcontroller as the main control chip and implements its control functions by extending a series of modules with the help of components such as sensors, motors and displays, thus realizing a fully functional and highly practical household massager. The paper also analyzes the possibility of intelligent control of the massager by a single-chip microcomputer. In hardware design, the minimum system of the microcontroller and its extension, the timing module, the display module and the temperature detection module are described in detail. In software, the functions are implemented by programming in C language. The design results show that the massager performs well in vibration massage, heat therapy and other functions. The design is relatively complete and the implementation scheme is simple and feasible. With software-based control, the temperature and the massage time can be displayed, and over-temperature alarm, vibration massage and heat therapy can all be realized, which improves the overall reliability and accuracy.

Keywords: STM32; massager; sensor; motor; display

1. INTRODUCTION

With the continuous development of modern society, people's living standards are rising day by day, and material enjoyment is no longer the only thing people care about: part of their attention has turned to improving the spiritual level and strengthening physical functions. Precisely for this reason, various health-care devices have emerged, such as massage beds, massage cushions, footbaths and so on [1], [2], [3]. Among them, the massager is widely welcomed in households for its well-considered design and powerful functions. Combining the advantages of meridian theory, bionics, ergonomics and Western health-care technology, the massager has its own unique advantages: it is light and simple, and it can provide functions such as tuina, acupressure, scraping, moxibustion-like heat and far-infrared vibration massage; it also offers automatic and manual working modes, and its functions are easy to extend, which makes it the best health-care product for hundreds of millions of families seeking health, leisure and well-being. Today's massagers are also becoming increasingly intelligent. As a micro-controller with high integration and stable performance, the single-chip microcomputer is widely used in all kinds of electronic products, and its powerful control capability and flexible programming characteristics make the intelligentization of household massagers possible [4], [5], [6].

There are many kinds of massagers on the market today, but most of them suffer from single functions, complicated operation and a low degree of intelligence. Therefore, developing a household massager based on a single-chip microcomputer that achieves diversified functions, convenient operation and intelligent control is of great practical significance and market prospect.

This design is a household massager based on the STM32F103C8T6 microcontroller. Taking the STM32F103C8T6 as the minimum system, a series of modules are extended outwards to realize functions in various aspects, mainly including the timing module, the display module, the temperature detection module and the body-part detection module, so as to realize vibration massage, heat therapy and other functions. The timing module provides real-time timing for the massager. The display module provides real-time

display and countdown display, helping users to follow the massage progress. The temperature detection module uses a temperature sensor for real-time temperature measurement. Body-part detection can sample the position and send the information to the microcontroller, thus meeting the user's need for massaging different body parts. A stepper motor is also used to simulate vibration massage, thus realizing the core function of vibration massage, while a relay and a heating pad are used to realize heating as an auxiliary heat therapy, so that the massager becomes multifunctional. Meanwhile, in order to ensure the safety of users, a temperature threshold is set and a buzzer gives an over-temperature alarm, which avoids harm to the human body caused by an excessively high temperature during massage and enhances safety.

2. OVERALL SYSTEM DESIGN

The system consists of the STM32F103C8T6 main control module, the timing module, the temperature detection and over-temperature alarm module, the key input module, the massage part detection module, the motor and heating module, the display module and the power supply. Its structural block diagram is shown in Figure 1.

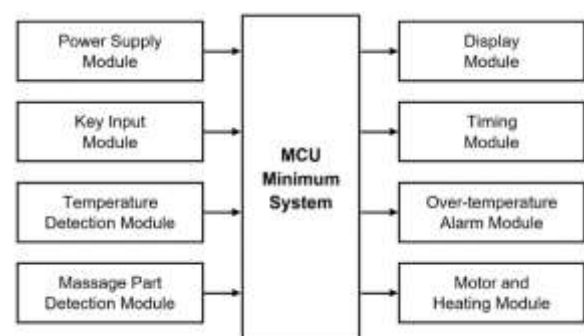


Figure 1 System block diagram

Initially the display shows the massage part, the massage countdown time, whether heating is on, the real-time temperature and the temperature threshold. One key controls whether the massage is started (the countdown begins once it has started), one key controls whether heating is on or off (this cannot be changed once the countdown has started), one key

controls the massage time (three levels: 5 s, 10 s and 15 s), and two keys adjust the temperature threshold (one increases and one decreases it; the threshold range is 0–99).

After starting, two infrared photocoupler pairs detect which part is being massaged. If no part is detected, neither motor rotates and the display shows “non”; if the leg is detected, the leg motor rotates and the display shows “leg”; if the arm is detected, the arm motor rotates and the display shows “arm”; if both are detected, the display shows “all” and both motors rotate. After starting, if the temperature is higher than the threshold, the buzzer alarms and the heating pad stops working; otherwise the buzzer does not sound, and when the countdown is over the buzzer also stops sounding.

3. HARDWARE DESIGN

3.1. Main Control Module

For a control system, the choice of processor is crucial, because factors such as its on-chip resources, its anti-interference capability and its operating speed all affect the implementation of the system, so the performance of the chip has to be considered comprehensively. This design requires a main control chip with a high main frequency, a fast processing speed, multiple peripherals and strong anti-interference capability, while also taking cost, performance and control speed into account. Finally the STM32F103C8T6 processor from ST, which is widely used and more reliable in practice, was selected.

The minimum system of the main control module consists of the microcontroller, the reset circuit, the download and debugging circuit and the crystal oscillator circuit. The microcontroller receives the 3.3 V operating voltage supplied by the power module in order to reduce power consumption, and filter capacitors are added to reduce the interference caused by power supply disturbances. According to the chip manual, this can be realized by a power-on reset circuit with an external reset (a low level on the NRST pin). The download circuit is realized through the SWD interface. Because not every application needs the full main frequency of the STM32, the device contains several clock sources internally; here the two external clocks are mainly introduced. The external clocks are generated mainly by two external crystals: the 8 MHz crystal provides the clock for the whole system, and the 32.768 kHz crystal provides the RTC clock. In addition, there are circuits for the system configuration control mode, which is configured by BOOT0 and BOOT1, and for the indicator lights.

- (1) The STM32F103C8T6 microcontroller, which has a Cortex-M3 core, uses ST's mature process and the Harvard memory architecture.
- (2) The STM32F103C8T6 medium-density microcontroller has single-cycle hardware multiplication and hardware division instructions, which makes control calculations convenient.
- (3) It is equipped with 64 K of Flash and 20 K of SRAM, and its main frequency can reach 72 MHz.
- (4) The microcontroller has sufficient digital peripheral interfaces (3 UARTs, 4 timers, 2 I2C, a CAN interface, 2 SPI and full-speed USB) and analog peripherals (a 12-bit, 10-channel ADC).
- (5) It can work in an industrial temperature range of -40°C to 85°C and has a strong anti-interference capability, especially against electrostatic interference.

3.2. Timing Module

This module realizes the massage countdown function of the massager, and the massage time is set to three levels, namely 5 s, 10 s and 15 s. It is described from the hardware and the software aspects. In the hardware part, the STM32F103C8T6

is used as the control core and is responsible for controlling the countdown of the whole massager, while the buttons are used to start or stop the massage and to set the countdown time. In the software part, initialization is carried out first, then the countdown is set: the massage time is set with the buttons and the set time value is loaded into the timer. Next comes the timer interrupt: one timer of the STM32F103C8T6 is configured to realize the countdown. When the timer finishes counting down, an interrupt is triggered to notify the microcontroller that the time has run out. Finally the microcontroller controls the display device to show the remaining massage time in real time. The specific procedure is as follows:

- (1) The massage time is set with the buttons.
- (2) The microcontroller loads the set time into the timer and starts the countdown.
- (3) During the massage, the microcontroller continuously checks the timer interrupt in order to determine whether the set massage time has been reached.
- (4) When the countdown is completed, the microcontroller stops the operation of the massager.

3.3. Temperature Detection and Over-temperature Alarm Module

This module realizes the temperature detection and over-temperature alarm functions of the household massager. In this design the temperature is measured by a DS18B20 temperature sensor, which is a digital temperature sensor produced by Maxim Integrated (formerly Dallas Semiconductor) and is suitable for various temperature measurement scenarios, while the over-temperature alarm is given by a buzzer. The DS18B20 communicates through a single-bus interface and outputs temperature data in digital form, so it is easy to integrate into digital systems and reduces the hardware cost at the same time. Its temperature measurement accuracy is relatively high, typically within $\pm 0.5^{\circ}\text{C}$, which makes it reliable in applications that require accurate temperature control. Digital temperature measurement systems built on single-chip microcomputers have also been widely used for low-power wireless temperature acquisition and transmission [7], [8]. The buzzer alarm circuit is a common audible warning device that can be found in many electronic products, such as computers, mobile phones and smart home devices; with such a circuit, the device can sound an alarm under specific conditions so as to remind the user to pay attention or to take appropriate action.

A temperature threshold is set during the design, and once the temperature exceeds the threshold the buzzer alarms. The DS18B20 digital temperature sensor is connected to a GPIO pin of the microcontroller and communicates through a single-bus interface. The buzzer is connected to another pin of the microcontroller to emit the over-temperature alarm signal. On the software side, the corresponding C programs are written to realize the following functions: first the DS18B20 sensor is initialized and parameters such as the temperature resolution are set; then the temperature data of the DS18B20 are read in a loop; finally, according to the read temperature data, a comparison is made and a judgement is given, that is, if the temperature exceeds the set threshold, the over-temperature alarm is triggered; when the alarm is triggered, the microcontroller controls the buzzer to sound the alarm and the massager stops heating. The specific procedure is as follows:

- (1) The massager is started first, and the microcontroller begins to run the program.
- (2) The microcontroller then initializes the DS18B20 sensor and reads the temperature data in a loop.

- (3) The comparison stage is entered, in which the temperature data that have been read are compared with the set threshold.
- (4) A judgement is then made: if the temperature exceeds the set threshold, the microcontroller triggers the over-temperature alarm and controls the buzzer to sound.
- (5) Finally the real-time temperature and the temperature threshold are displayed on the screen, so that the user can see the current temperature situation at a glance.

With this method, the microcontroller and the DS18B20 can realize real-time temperature detection and over-temperature alarm for the massager: not only can the current temperature be known, but the temperature threshold can also be set, and safety is guaranteed at the same time.

3.4. Key Input Module

In all kinds of electronic devices and systems, the key input circuit plays an important and indispensable role. It builds a bridge of information between the user and the device: it receives the key operation commands of the user and converts them into electrical signals that are transmitted to the control system of the device. The core of the key input circuit is the key switch, which usually consists of metal contacts, a spring and other parts. A key is a switching device made up of two or more contacts; pressing the key closes the contacts and thus sends a signal to the circuit. A key may be of the normally closed type (closed when pressed) or of the normally open type (opened when pressed), depending on the design requirement. When the user presses the key, the metal contacts close and a conducting path is formed; when the key is released, the metal contacts open and the path is broken. The on-off state in this process can be detected by components such as resistors and capacitors in the circuit and is then converted into an electrical signal output. In order to prevent the key from drifting or causing misoperation when it is not pressed, pull-up or pull-down resistors are often used when the key is connected to the circuit: a pull-up resistor is connected between the key and the positive supply, whereas a pull-down resistor is connected between the key and ground. Their function is to keep the key in the expected logic state (high or low level) when it is not pressed. When designing a key input circuit, both the requirements of the device and the application scenario have to be considered. Choosing an appropriate key type, such as a single key, several keys or a key combination, all of which have their own uses, can implement the desired functions more easily and save trouble. In addition, the basic architecture of the circuit has to be determined, including the connection of the key switches, the signal detection circuit and the filter circuit [9], none of which can be ignored. At the same time, possible interference sources in the circuit, such as electromagnetic interference and electrostatic interference, have to be taken into account, so that corresponding anti-interference measures can be taken in advance to ensure the stability and reliability of the circuit.

There are five keys in this design, which are used respectively to start the massager, to switch heating on or off, to adjust the massage time, to raise the temperature threshold and to lower the temperature threshold, and a combined debouncing method is adopted for the keys so as to eliminate the contact jitter [10].

3.5. Massage Part Detection Module

This module realizes the function of detecting the part being massaged. A Hall sensor was originally intended for this detection, but in view of the cost, the ease of implementation and the replaceability of the function, infrared photocoupler pairs are used to detect the massage part in the physical implementation. Two parts, the arm and the leg, are distinguished, and whichever part is detected is massaged.

An infrared photocoupler pair, also called an infrared through-beam sensor, an infrared through-beam module or an infrared remote-control pair, is a common infrared sensor used to detect infrared signals within a certain range in the environment, and sensor-based monitoring schemes of this kind have also been applied to industrial equipment, such as the tear monitoring of high-strength conveyor belts [11]. As the name implies, such a pair usually consists of an emitting tube and a receiving tube, and its working principle is mainly related to the emission and reception of infrared rays. Its structure is generally not complicated and mainly includes the emitting tube, the receiving tube and the supporting structure. The emitting tube is usually an infrared emitting diode, which emits infrared rays of a specific frequency: when current flows through the emitting tube, infrared rays are emitted, propagate through the environment and are reflected or blocked by the target object. The receiving tube is usually an infrared receiving diode, which can detect infrared rays in the environment and produces a current when infrared rays fall on it. Because the structure of the infrared photocoupler pair is relatively simple, it is easy to integrate with other electronic components while reducing the complexity of the system. Its stability is also relatively high: it works normally in different environments and has a strong anti-interference capability, so that the reliability of data transmission is guaranteed.

When an infrared photocoupler pair is working, the emitting tube emits infrared rays, which propagate in the environment and are reflected or blocked by the target object; the receiving tube receives the reflected or blocked infrared rays and produces a corresponding current signal [12]. By detecting the change in the current of the receiving tube, the presence, the distance or other features of the target object can be determined. In this design, when the photocoupler pair that represents the arm is touched, the arm is sensed and the signal is sent to the microcontroller for decision-making; the same applies to the pair that represents the leg.

3.6. Motor and Heating Module

This module is the core module for the main massage functions, and it realizes the vibration massage function and the heat therapy function. In this design the rotation of a stepper motor represents vibration massage, and a relay controlling a heating pad represents heat therapy.

A stepper motor is a motor whose motion proceeds in fixed steps: each step is discrete rather than a continuous rotation. Its motion is driven by the input electrical pulses, and each pulse turns the motor through a certain angle, so a stepper motor is very suitable for applications that require precise control of the rotational position and speed. The structure of a stepper motor consists of a rotor and a stator [13]: the rotor is usually made up of several electromagnetic coils distributed at fixed angles and forming one or more “steps” or “phases”, while the stator usually consists of one or more permanent magnets fixed in the motor housing. Stepper motors have the advantages of high accuracy, good reliability and simple control, and practical stepper motor control systems based on a single-chip microcomputer have been developed accordingly [14].

A relay is an electrical switch that opens or closes one or more other circuits by controlling the on-off state of an electromagnetic coil. Relays play an important role in electrical systems, where they are used to transfer signals between different circuits, to control currents or to implement logic functions; their main roles are isolation, conversion and making or breaking a circuit. Relays are of many types: according to their application and structure, they can be divided into electromagnetic relays, solid-state relays, thermal relays, time

relays and so on [15], [16], and each type has its own functions and range of application.

A heating pad is a device that generates and supplies heat, and it can be found in many circuit structures, both in household appliances and in industrial equipment. Heating pads are available in several forms, and which one is used depends on the specific application and heating requirement. Common heating pads include resistance heating pads, heating coils and heating films. A resistance heating pad is made of conductive material, which may be a metal or an alloy wire, and heat is generated when a current flows through the heating element. For pure resistance heating, the temperature is usually controlled by switching the supply on and off [17].

The microcontroller is connected to the pins of the stepper motor driver chip; depending on the switch states, the microcontroller outputs different level signals, thereby controlling the stepper motor to rotate or to stop. Heat therapy is realized by the microcontroller sending a signal that controls a heating tube through a relay. In the physical implementation, one 5 V relay is used to control a resistive heating pad, which completes the heating function. For the motor vibration part, the circuit is connected first: the stepper motor is connected to the microcontroller and the driver chip L298 is used to increase the output current. A four-phase stepper motor is adopted, each phase of which is connected to an output pin of the driver chip, and the microcontroller generates pulse signals to control the rotation of the stepper motor. As long as the microcontroller sends the signals in the correct pulse sequence, the stepper motor can be controlled to rotate clockwise or counter-clockwise. According to the type of stepper motor, full-step or half-step mode can be chosen to control the rotation accuracy and the speed. With C language programming, the program has to consider parameters such as the model, the rotation angle, the speed and the acceleration and deceleration of the stepper motor, as well as the correct pulse sequence and control logic. This design only uses the microcontroller to control the rotation of the stepper motor and does not focus on the rotating speed and the frequency.

3.7. Display Module

This module displays the key information during the massage, including the temperature measured by the sensor, the temperature threshold, the massage countdown, the massage part and whether heating is on. Display devices such as character liquid crystal displays have long been used in instruments and meters to present measurement results [18]. In this design an OLED display is adopted because of its small size and low power consumption, and the microcontroller communicates with it through the I2C protocol.

4. SOFTWARE DESIGN

4.1. Main Program Design Flowchart

The workflow of the system program is as follows: first the system is powered on and reset, then the OLED display, the timers, the keys and other modules are initialized; next the temperature threshold, the heating state and the massage duration are set. Once key K1 is pressed, the massage countdown state is entered; during this period, whichever part is detected is massaged, and at the same time the current temperature is compared with the temperature threshold, so that an alarm is given and heating stops as soon as the temperature is higher than the threshold. Finally, when the massage countdown ends, the massage stops. The main program design flowchart is shown in Figure 2.

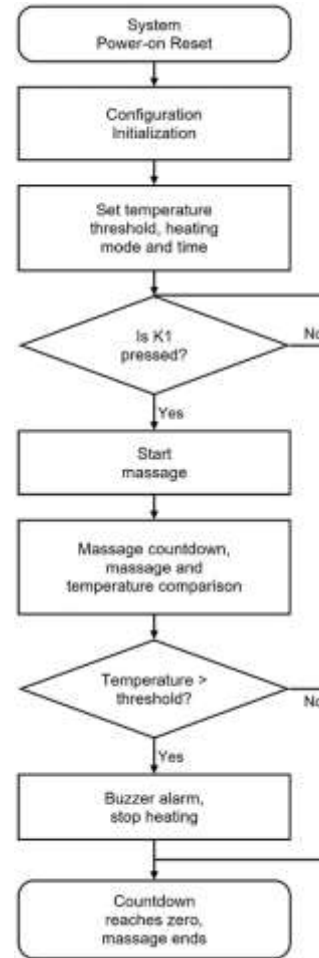


Figure 2 Flowchart of the main program design

4.2. Interrupt Service Routine Design Flowchart

In this design the massage countdown function is realized by the timer interrupt function of the microcontroller. First the microcontroller and the peripherals are initialized, then the timer and I/O port configuration is designed, then the initial countdown time is set and the timer is started; once an interrupt is triggered, the remaining massage time is decreased until the massage ends. The flowchart is shown in Figure 3.

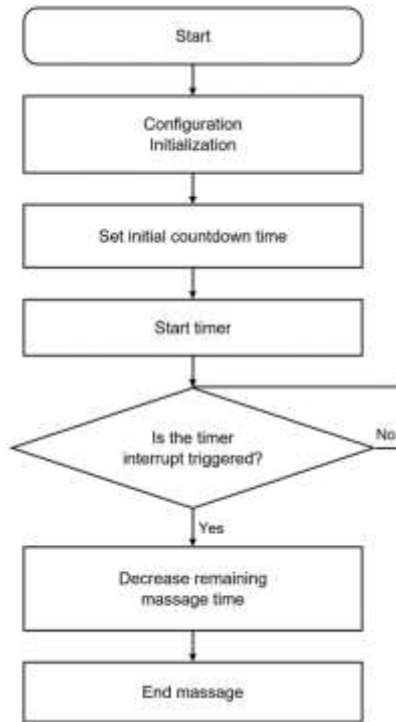


Figure 3 Flowchart of the interrupt service routine

5. PROTOTYPE FABRICATION

The timing module, the temperature detection and over-temperature alarm module, the key input module, the massage part detection module, the motor and heating module, and the display module were soldered together. After the system had been powered, experiments and debugging were carried out and the code was burned into the microcontroller. The prototype that was built is shown in Figure 4.



Figure 4 Prototype of the STM32-based massager

6. CONCLUSION

The design of this STM32-based household massager basically realizes the common functions of a massager: the temperature can be measured and displayed on the screen; the heating state can be changed with the keys and displayed; the arm and the leg can be detected and the part information can be displayed; the temperature threshold can be set with the keys during use and displayed; an over-temperature alarm can be given through the buzzer; and after a part is detected the motor rotates

correctly, the heating pad heats normally, and both the vibration massage and the heat therapy functions are basically realized. The system has a reasonable structure and complete functions, with good practicability, expansibility and reliability, and has value for popularization and application.

7. REFERENCES

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