Portable low intensity focused ultrasound therapy device

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Abstract

With the development of social economy, people's work pressure and mental stress are getting bigger and bigger, and lack of exercise leads to various soft tissue injuries in the body. For this reason, a portable low-intensity focused ultrasound therapy device is designed. It uses a 9 V rechargeable lithium battery as the power supply. The TLV70033 and TLV61220D regulators provide 3.3V and 5V respectively for the circuit. The STM32L151 controls the DDS signal generator to generate a 2 MHz square wave, which is divided by the D flip-flop. The UCC27525 drives the MOS tube, and combines the PID algorithm to control the PWM wave of the single chip microcomputer to control the output ultrasonic intensity to be 0.3 mW/cm2, 0.5 mW/cm2, 0.8 mW/cm2, 1 mW/cm2, and the frequency is 1 MHz. The road drive circuit can realize the treatment of two different parts at the same time; The focusing function is achieved by a special concave piezoelectric ceramic piece. The device has the advantages of small volume, light weight, low cost, no coupling agent, good focusing and portability.

Keywords

Portable device; Focused ultrasound; Ultrasound therapy; Soft tissue pain.

1. Introduction

With the development of society and science and technology, more and more people are addicted to the network and work. When they face the computer for a long time, the work pressure and mental stress are increasing. Due to the lack of exercise, the body bones and soft tissues become fragile and often appear chronic. Soft tissue pain [1, 2].

It has been proved by a large number of clinical experiments that low-intensity focused ultrasound has better focusing, penetrating and anti-attenuation, which can effectively shorten the treatment cycle for the treatment of chronic soft tissue diseases, and has a quick effect [3, 4, 5, 6]. Low-intensity focused ultrasound therapy is to use its own mechanical, thermal, and physicochemical effects to alleviate local swelling and pain caused by accumulated strain [7]; relieve muscle spasm, relieve tendon and ligament due to aseptic inflammation Adhesion; promotes repair of broken muscle fibers; Promote the repair of damaged joint soft palate, relieve joint movement disorders, inhibit the development of ankle arthritis [8, 9].

At present, the ultrasonic treatment devices on the market generally have a large volume, need to use a couplant, and the price is relatively expensive. The portable low-intensity focused ultrasound therapy device for treating soft tissue pain is very scarce. Therefore, this article will design a portable focused ultrasound therapy device that treats soft tissue pain. The device has the characteristics of low cost, small volume, light weight, good focusing, no coupling agent and convenient carrying.

2. Parameter setting basis

The intensity of the ultrasound affects the effect of the treatment and the amount of heat generated, while the ultrasound frequency is the depth that affects the penetration of ultrasound [10], and it is important to choose the appropriate ultrasound dose for the treatment of soft tissue disease. Based on portable chronic soft tissue injury treatment equipment, its requirements are safe, effective, and long-term use [11].

2.1 Security

Ainsworth et al [12] used ultrasound to treat 113 patients with shoulder pain at a dose of 1 to 3 MHz, 0.5 W/cm^2 for 4.5 min each. After 6 weeks of treatment, the patient's pain score decreased significantly. Feng Jilin et al [13] in the clinical application of ultrasound treatment of 52 patients with flaccid disease, treatment in the focal area and the corresponding segmental nerve root zone of the affected side, using pulsed, contact movement method, dose 0.5~1.0 W/cm^2 The time depends on the extent of the lesion, usually 10~15 min. After 5 treatments, the analgesic effect is obvious. The strength can be considered 300-1000 mW/cm^2 - a temperature rise of less than 5 degrees Celsius is considered to be a safe range for ultrasonic irradiation.

2.2 Frequency and effectiveness

Treatment of knee arthritis at a frequency of 0.8 MHz found that the relief of pain symptoms was as high as 76% [14]. 2.95MHz frequency, the relief rate for the oblique muscle pain is only 16% [15]; For the relief of myofascial pain, the pain in female and male patients decreased by 57% compared with baseline, 78% [16]. The possible reason is that lower frequencies can lead to better penetration depth (the theoretical frequency of 1MHz is 5cm deep in the skin), fasciitis and tendon damage are shallow and the lesions of knee arthritis are deep. Higher frequencies may not reach the depth of treatment [17]. Therefore the preferred frequency is 1 MHz.

2.3 System hardware design

The hardware device is mainly composed of a main control chip, a power supply circuit, a DDS signal generation circuit, a drive circuit, an impedance matching circuit, and a low-pass filter circuit, as shown in the hardware structure diagram of Fig. 1.

The control circuit is composed of the main control chip STM32L151 low-power ARM MCU and buttons. The control chip has a clock frequency of up to 32MHz and has SPI function, which is of great significance for adding LCD screen in the future. The power supply circuit is provided with 3.3 V, 5 V, and 9 V by the TLV70033 and TLV61220D voltage regulator chips and the boost boost chip for the single chip circuit, the DDS signal circuit, and the drive circuit, respectively. The DDS signal generation circuit combines the AD9833 with a D flip-flop to generate a stable square wave of 1 MHz frequency. The main controller generates a PWM wave of 1 MHz. The PID algorithm is used to adjust the duty ratio within a certain range, and the enable end of the MOS tube driver UCC27525 is controlled to realize the control of the output ultrasonic intensity. The impedance matching circuit is matched by an inductor and a capacitor according to the output current and the impedance of the piezoelectric ceramic piece to a circuit of about 30 ohms. The low pass filter circuit is a simple filter circuit composed of a resistor capacitor. Finally, the ultrasound output is 0.3 mW/cm^2, 0.5 mW/cm^2, 0.8 mW/cm^2, 1 mW/cm^2 in four positions, and the frequency is 1 MHz.

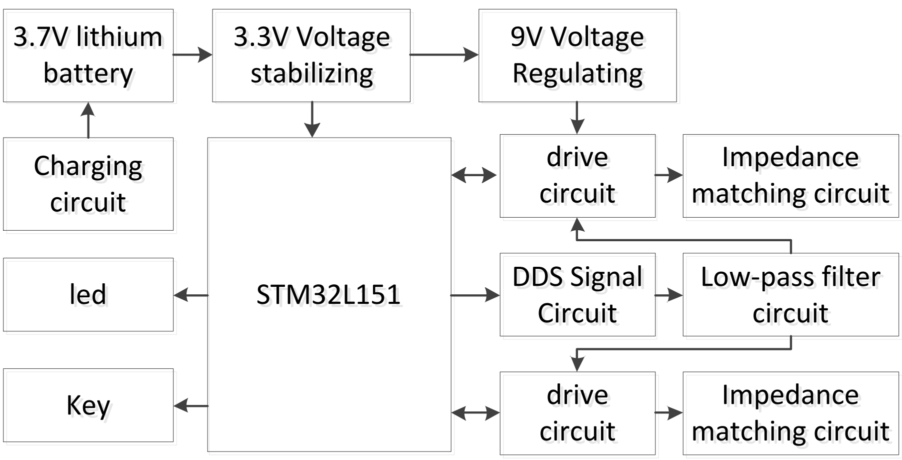

Fig. 1 Hardware structure diagram

3. Software programming

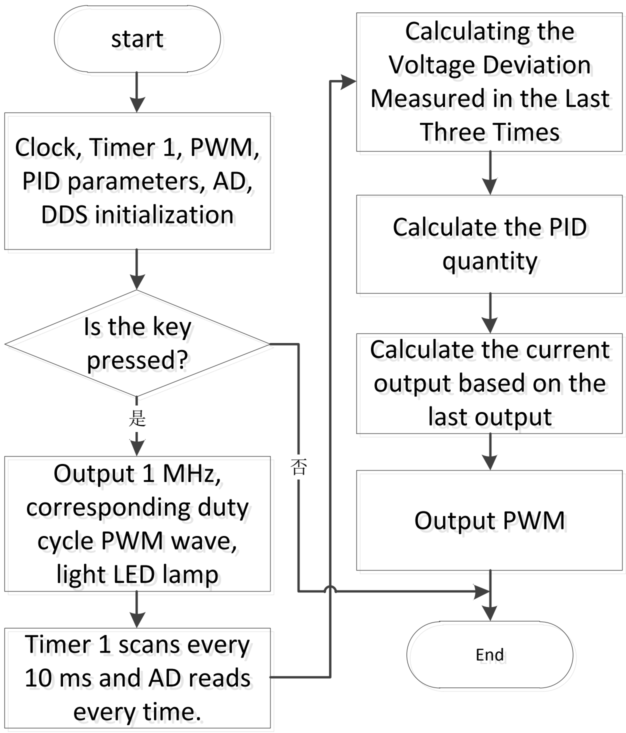

Fig. 2 Flow chart of ultrasonic generator

The STM32L151 program includes initialization of clock, timer 1, PWM, PID, AD, LED, DDS, and cyclic monitoring to see if there is a button press. When there is a button press, the corresponding command function is executed by the switch, and the PWM wave of the corresponding gear duty ratio is output, and the corresponding led lamp is lit, and the timer 1 is interrupted every 10 ms, that is, the AD reads the output voltage of the driver once. Then store the data in the register, calculate the deviation value of the three measurements before and after, and then multiply the corresponding coefficient KP, KI, KD to find the PID, and finally the PWM output duty of the current output from the last output. So that the output ultrasound intensity reaches a steady state. The flow chart is shown in Fig. 2.

4. Parameter calculation

4.1 Principle of PID Control

In this paper, incremental PID algorithm is used to obtain the incremental u(k) of duty cycle of the output PWM according to the difference between the voltage value collected by A/D and the preset value. The control formula of incremental PID is as follows:

$$\Delta u(k) = u(k) - u(k-1) = K_P \Delta e(k) + K_I e(k) + K_D[\Delta e(k) - \Delta e(k-1)] \quad (1)$$

Formula:$\Delta e(k)=e(k)-e(k-1)$, is the output of the controller. is the output voltage error of the driver. K_P is proportional amplification coefficient. K_I is the integral coefficient. K_D is a differential coefficient. The system structure is shown in Fig. 3, and the control process is described as follows:

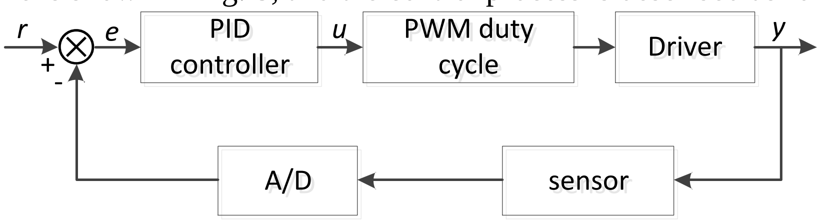

Fig. 3 PID system structure

Note: r is the preset effective voltage value; e is the deviation between the preset effective voltage value and the actual output effective voltage value; u is the output value of the PID controller; y is the actual output effective voltage value of the system.

Firstly, the actual output voltage value of the driver is fed back to the A/D port of MCU through the sensor. The deviation e(k) is obtained by the difference between the voltage value converted by A/D and the preset value R. E(k) is used as the input of PID, and the duty cycle of current output PWM is obtained by adjusting the output effective voltage value.

4.2 Calculation of Ultrasound Parameters

This design is limited by the wearable node shape, the size needs to be very small, and the battery energy needs to be 2000 mAh. Therefore, it is necessary to transform the electric energy into ultrasonic energy as efficiently as possible, and transfer most of the energy to human tissues. A drive circuit with low output impedance conversion efficiency of more than 90% is needed.

According to the above clinical research and the safety, effectiveness and long-term use of wearable soft tissue injury treatment equipment, it is concluded that the frequency of output ultrasound is 1MHz, the intensity is 300-1000mW/cm^2, and the transducer uses a circular piezoelectric ceramic plate with a diameter of 2cm. The calculation formula of output ultrasonic power is as follows:

$$P = \frac{V^2}{R} = \frac{(\frac{V}{\sqrt{2}})^2}{R} \tag{2}$$

In the model, R is the resistance of piezoelectric ceramic (usually 10-15 Ohm), V is the AC voltage output to piezoelectric ceramic, P is the ultrasonic output power, that is, P=300 mW/cm2*3.14*12 =0.942 W. Considering the actual circuit loss, the power supply voltage is 9 V, and the effective voltage acting on the transducer is controlled by PWM wave to ensure that the output of the transducer is 300-1000 mW/cm^2, and according to the conversion efficiency. If the rate is higher than 60%, the electric power is less than 1.8 W.

4.3 Structural Design of Acoustic Conduction Path

In order to avoid ultrasonic reflection and minimize ultrasonic energy loss, the ultrasonic transducer is fixed. In addition, in order to abandon the traditional coupling agent, a polyphenylene polymer which can be reused many times will be attached to the surface of the transducer. The polymer has a certain stickiness. When dust is adhered to the surface, it can be washed with water and reused.

5. Experimental results and data analysis

5.1 Power consumption test

Wearable devices require as long as possible. For this reason, STM32L151 is used as the main control chip, and the power consumption of remote controller is very low. The power consumption of supernatant generator is discussed in four modes: standby mode, low-intensity ultrasound output, medium-intensity ultrasound output and high-intensity ultrasound output. The power consumption test results of Table 1 are obtained by measuring the ultrasonic generator with the DC voltage stabilized power supply of Model DPS-3005D. The QI standard wireless charging module is used for charging. The voltage is 9 V, the maximum current can reach 1.5 A, and the actual charging time needs 2 hours to be full. It can work continuously for about 2 hours in maximum power consumption mode.

Table 1 Device power test results

Working mode	Input voltage (V)	average current (mA)	Average power (mW)
low	9	56	500
medial	9	92	833
Medium-high	9	148	1333
high	9	186	1667

5.2 Output Ultrasound Testing

PWM wave drives piezoelectric ceramic sheet to produce ultrasound, changes duty cycle, and controls the output ultrasonic intensity. The output waveform is shown in the output waveform of Fig. 4 driver. The frequency is 1 MHz, and the error is 0.004 MHz. The ultrasonic intensity is measured by acoustic power meter in four grades: 0.3 mW/cm^2, 0.5 mW/cm^2, 0.8 mW/cm^2 and 1 mW/cm^2. The error is 0-5 mW/cm^2.

5.3 Therapeutic effect test

Six people were selected as experimental treatment samples, and treated with the wearable low intensity focused ultrasound rehabilitation patch designed in this paper through the traditional Chinese medicine rehabilitation intelligent physiotherapy box. The treatment time was 15 minutes each time and the treatment lasted 10 days. Compared with the treatment results, the rehabilitation patch treatment effect was better and obvious, and the pain was significantly reduced.

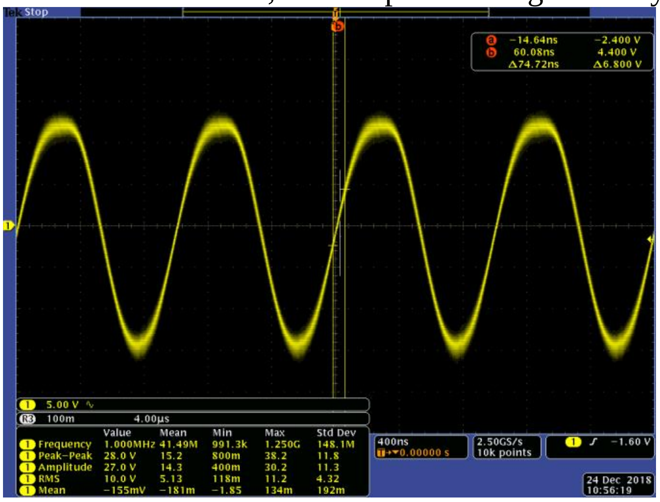

Fig. 4 Driver output waveform

6. Conclusion

STM32L151 with low power consumption is used as the main control chip for wearable low intensity focused ultrasound therapy rehabilitation paste. Through test and analysis, the device uses QI standard wireless charging module to charge, charging time needs 2 hours to fill, and continuous use can reach 2 hours. The integrated Boost boost circuit with conversion efficiency up to 95% provides 9 V voltage for the driver, and then the MCU combines with PID algorithm to output PWM wave. The driver-driven transducer is controlled to generate frequency of 1 MHz, intensity of 0.3 mW/cm^2, 0.5 mW/cm^2, 0.8 mW/cm^2, 1 mW/cm^2 four-level ultrasound, which makes the electro- acoustic conversion efficiency up to about 60%. The use of polyphenylene polyolefin polymer instead of the traditional coupling agent, there is no trouble in using the coupling agent before each time, so that ultrasound treatment is more convenient and efficient.

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