Research and implementation of single point focusing system based on planar array ultrasonic transducer

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Abstract. Ultrasound hyperthermia treatment is an advanced method of tumor treatment developed in recent years. Different from traditional tumor cutting and chemotherapy, it has the advantages of non-invasive, reducing patients' pain and recovery time. The focus of ultrasound is one of the key technologies of this treatment technology. In this paper, a phased array ultrasound focus system is designed. Combined with the 256 element planar array ultrasonic transducer, the single point focus and three-point focus of ultrasound are realized by using time inversion method. The intensity distribution map is drawn by MATLAB, and the actual intensity distribution is detected by using the horizontal plane, which verifies the correctness of the method it can enhance the energy density of the emitted ultrasound and shorten the treatment time.

1. Introduction
Tumor is one of the main culprits that directly threaten people's life and health [1]. At present, there is no effective way to cure cancer. Once found, only through chemotherapy, resection and other methods for treatment. Sometimes these methods have little effect and even bring direct damage to the patient's body [2]. In the 1990s, thermal ablation technology, laser technology, radio frequency technology, etc. rose rapidly, and gradually applied to clinical treatment, but there are certain limitations in technology, such as repeated treatment, long treatment time, lack of effective monitoring in the treatment process and so on [3].

Ultrasound hyperthermia treatment is a new and effective method of tumor treatment. Through the heat effect of ultrasound focusing, the tumor area of patients should be heated, so that the tumor cells in the focus area will be heated and necrotic in a short time, so as to achieve the purpose of eliminating the tumor, and then relying on the patients' own repair to make the focus disappear [4]. Compared with other technologies, ultrasound hyperthermia treatment has obvious advantages: it can effectively kill tumor cells in a non-invasive way; because the focus can be controlled very little, it can kill cancer cells to the maximum extent without damaging normal cells, and the safety is guaranteed.

2. Ultrasonic phase control system
At present, ultrasonic focusing is mainly realized in three ways: spherical self-focusing [7], acoustic lens focusing [8] and phased array focusing. Among them, the spherical self-focusing adopts concave spherical ultrasonic transducer, and the acoustic wave is focused through concave convergence [9], which has the disadvantages of complex operation and unchangeable focus position; the acoustic lens
focuses the acoustic wave which does not have focusing characteristics originally by using the acoustic lens, so as to achieve the purpose of focusing, which is more flexible than the spherical self-focusing [10]; the phased array focuses by using multiple ultrasonic transducers By using the phase difference of different ultrasonic transducers to focus [10], the focus can be moved by changing the phase difference of ultrasonic transducers. In this paper, phased array focusing method is used to focus ultrasound [11].

2.1. Transmitter design
In this paper, a 256 element planar array ultrasonic transducer with a resonant frequency of 1.04 MHz is used. All array elements are embedded in the designed base frame, forming a 16*16 array in XY plane, and the dimension of the vibration element is the same as that of the base frame. The shelf of the experimental material is composed of four 3D printing pillars and a hollow shelf. The shelf is covered with a preservative film to support the experimental material. In order to ensure the smooth progress of ultrasonic focusing and prevent the impact of ultrasonic reflection on the emitter, the whole emitter must be placed in the water during the experiment, so the emitter is designed to be waterproof. See Figure 1 for the simulation diagram and the real object diagram.

![Figure 1](image1.png)

(a) (b)

**Figure 1.** (a) is the simulation diagram of 16*16 ultrasonic transducer, and (b) is the actual diagram of the transmitter and bracket.

2.2. Signal generator design
In this paper, FPGA is used to control DDS to generate signals. The FPGA uses kc705 development board, which has an LPC and HPC interface. The total number of I / O ports available is 228. DDS adopts AD9959 chip, which inherits four complete DDS and integrates several analog-to-digital converters at the output end. AD9959 chip has up to 16 levels of frequency, phase and amplitude modulation, 14 bit phase offset resolution and 10 bit output amplitude resolution. The 16 * 16 transducer array needs 256 DDS, namely 64 AD9959 chips and 4 FPGA development boards. The structure diagram of the signal generator is shown in Figure 2.
Driven by the reference frequency clock, the FPGA development board sends a frequency control word (FCW) to DDS, and DDS starts to work. When a reference clock arrives, the phase accumulator in DDS accumulates the FCW and the output value of the register, inputs the added result into the register, and the accumulation register transmits the data generated when the last reference clock acts to the accumulator through feedback. Under the clock, FCW is accumulated continuously, and the data output by the phase accumulator is used as the address. By looking up the amplitude table corresponding to the address in the waveform memory, the conversion from phase to amplitude can be completed. Then the pure signal is output by DAC and LPF.

### 2.3. Impedance matching

If the signal generator and ultrasonic transducer are directly connected with the same axis, the problem of impedance discontinuity will be encountered in the process of signal transmission, and further lead to the reflection phenomenon between the terminal and the source, resulting in the signal ringing distortion, so it is necessary to match the impedance between the signal generator and ultrasonic transducer to reduce the impact of signal transmission.

Impedance matching is to insert a passive network between the source and the terminal to make the terminal impedance reach 50 ohms, so as to complete the source matching. In this paper, the transformer is used as a passive network, the core of the transformer is ferrite magnetic ring, and the terminal impedance network before and after matching is shown in Figure 3.

**Figure 2.** Structure of signal generator.

**Figure 3.** The left is before impedance matching, the terminal impedance is 26.818-j208.59ohm; and the right is after impedance matching, the terminal impedance is 54.385-j0.70652ohm.
3. Ultrasonic single point focusing

3.1. Ultrasonic focusing technology

The most important area of medical ultrasound is the focus area with high concentration of acoustic energy. Focal region refers to the spatial body within the -6dB sound pressure range containing the focus of sound pressure, so the three-dimensional shape of focal region is oblong ellipsoid. The size of focal region is usually represented by the size of two sections, including three data, namely focal region length, focal region section length and focal region section width, as shown in Figure 4.

![Focal region three-dimensional shape](image_url)

Figure 4. Focal region three-dimensional shape, where PQ is focal region length, AB is focal region section length and Mn is focal region section width.

There are two main methods to realize ultrasonic focusing technology, namely pseudo inverse matrix method and time inversion method. The process of the pseudo inverse matrix method is to first set an initial sound pressure for the building point, then inverse the forward propagation operator of the sound wave matrix, and then multiply the inverse matrix with the preset sound pressure to get the phase and amplitude of each element in the ultrasonic phased array. This method needs to get the propagation operator of the sound wave in advance, which will cause great error to the ultrasonic transducer with large size, but the time inversion method solves this problem. Now, an acoustic emission source is placed at the preset focus, and the ultrasonic transducer is used as the receiving detector to record the phase and amplitude of the signals of each vibration element arriving at the receiving detector, and the reversibility of the ultrasonic is used to obtain the phase and amplitude required for focusing. Therefore, in this paper, time inversion method is used to obtain ultrasonic focus data. Single focus and three-point focus data are shown in Table 1 and table 2 respectively. The single focus depth is 60mm, and the three focus depth is 50mm, 60mm and 70mm respectively.
### Table 1. Single focus data.

| Channel | Freq (Hz) | Amp (mv) | Phase (°) |
|---------|-----------|----------|-----------|
| 1       | 1040000   | 137      | 241       |
| 2       | 1040000   | 159      | 35        |
| 3       | 1040000   | 180      | 217       |
| 4       | 1040000   | 199      | 66        |
| 5       | 1040000   | 215      | 305       |
| ……      | ……        | ……       | ……        |
| 256     | 1040000   | 137      | 241       |

### Table 2. Three focus data.

| Channel | Freq (Hz) | Amp (mv) | Phase (°) |
|---------|-----------|----------|-----------|
| 1       | 1040000   | 101      | 209       |
| 2       | 1040000   | 90       | 97        |
| 3       | 1040000   | 97       | 318       |
| 4       | 1040000   | 118      | 51        |
| 5       | 1040000   | 239      | 294       |
| ……      | ……        | ……       | ……        |
| 256     | 1040000   | 153      | 198       |

#### 3.2. Focusing experiment design

The experimental scheme of single point focusing is shown in Figure 5.

The focus center is on the same horizontal plane as the water surface, the ultrasonic transducer is placed in the water, and the distance between the transmitting end and the water surface is 60mm.

The experimental scheme of three-point focusing is basically the same as that of single point focusing, and the distribution of the set three focuses is shown in Figure 6.

The three focuses are on the same coronal plane, the horizontal distance between the adjacent focuses is 10 mm, the vertical distance between the focus centers is 10 mm, and the distance between the center of the focus in the middle and the transmitting end of the ultrasonic transducer is 60 mm.

![Figure 5. Design scheme of single point focusing experiment.](image-url)
3.3. Focusing results and analysis

Single point and three-point focusing are simulated by MATLAB software respectively. Because of the mechanical effect of ultrasonic wave, when it passes through the medium plane, it will cause the mechanical movement of the material. Therefore, the two schemes carry out the water surface experiment respectively. When ultrasonic wave passes through the medium surface of water air, it will cause the water flower similar to the distribution of sound field on the horizontal plane. The simulation results and water surface experiment results are shown in Figure 7.

It can be seen from Fig. 7 (a) and (c) that the focus energy concentration of single point focus (the stronger the energy of the position with the red color), the focal spot diameter is about 3mm, and the energy distributed outside the focus is less, presenting as a pure blue (the energy is extremely low). In the corresponding water surface experiment, the height of the water flower reaches nearly 50mm (the part of the water flower near the water surface in the figure), and it is attached to the water surface. The near atomization effect shows that the acoustic energy is concentrated and the intensity is high at the focus of single point focusing. (b) and (d) in Fig. 7 are the experimental results of three-point focusing. It can be seen that the energy of the three focuses is the largest in the middle focus, and the energy of the two sides is slightly small, so the experimental results are correct. The water spray distribution in the water surface experiment can also be seen that the water spray in the middle focus is significantly higher than that on both sides, which also verifies the theory that the energy at the center of the focus is the strongest. However, the energy concentration of three-point focus is worse than that of single point focus. In addition to the energy concentration at the focus, there is also a small amount of acoustic energy distribution outside the focus, which is light colored fog.
Figure 7. (a) is a single point focused MATLAB simulation sound field with the focus at (0,0), (b) is a three-point focused MATLAB simulation sound field with the focus at (-10,0) (0,0) (10,0), (c) is a single point focused water surface experiment diagram, and (D) is a three-point focused water surface experiment diagram.

4. Conclusion

Ultrasound hyperthermia treatment is a new type of tumor treatment method. It uses the characteristics of ultrasound, such as deep penetration, good directivity and good focalization. It emits hundreds of ultrasound beams in vitro and focuses directly on the pathological tissue in vivo. In this paper, we first discuss the various focusing methods of ultrasound, and design the ultrasonic phase control system by using phased array focusing. We introduce two kinds of ultrasonic focusing algorithms: pseudo inverse matrix method and time inversion method. We get the phase and amplitude data of single point and three-point focusing by using time inversion method, and realize the single point focusing and three-point focusing of ultrasound by using MATLAB software and water surface experiment. Among them, single point focusing has a good energy concentration, and the energy concentration of three-point focusing is slightly worse than that of single point focusing, which needs further study.

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