Research on Photoacoustic Imaging System Based on Delay Sum Algorithms

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Abstract

Photoacoustic imaging technology plays a very important role in medical imaging research. It uses laser pulse as a source of signal to illuminate the object to be detected, makes the vibration of the object emit sound wave as a signal, and finally reconstructs the internal image of the object by obtaining the signal information, so as to achieve the purpose of detecting the internal structure of the object. This paper designs and studies the experiment based on the theoretical basis, and reconstructs the image of the experimental sample according to the designed experimental platform and experimental algorithm, so as to verify the reliability of the experimental platform. At the same time, the problems arising from the experimental results are dealt with. There are artifacts in the image results, and the clarity and quality are not high. For these problems, the wavelet threshold is used first. According to this method, we can see that the image after wavelet threshold processing is better than the original data. Then we use the bilateral filtering algorithm to process the image, which makes the image clearer and the quality of the image better, and is more conducive to the judgment of experimental detection.

Keywords

Photoacoustic Imaging, Delay Summation, Wavelet Threshold Transform, Bilateral Filtering Algorithms.

1. Introduction

Photoacoustic imaging is actually the transfer of energy. The energy of light is transferred to another object, which makes certain changes in some characteristics of the object. When the canceration and mutation of experimental objects and human tissues occur, the light absorption ability of different parts is different, and then the characteristics and characteristics are reflected according to the light absorption ability of different parts. The absorption of light by the cancerous part of human tissues is much greater than that of normal tissues[1].

When the experimental object or tissue absorbs laser energy, it absorbs enough heat, and then expands, produces fine vibration and emits sound waves. At this time, the ultrasonic probe is used to detect and save the collected data. Then the program is written according to the image reconstruction algorithm, and the collected data is imported into the program for image reconstruction. According to the theoretical basis, the corresponding experimental platform is designed, the experimental system is built, and the simulation experiment is carried out according to the experimental system, which verifies the reliability of the experimental platform system. Meanwhile, according to the deficiencies of image reconstruction generated by the simulation experiment, methods are found to improve and improve.

2. Theoretical Basis of Photoacoustics

The most important and basic principle of photoacoustic imaging is photoacoustic effect. Light produces related changes when it acts on biological tissues. The basic parameters of photoacoustic imaging in biological tissues include absorption coefficient, reflection coefficient, scattering coefficient and anisotropy factor[2]. Biological tissues absorb the energy of light and then change, which is the characteristic basis of photoacoustic effect.

Among the biological tissues and the objects to be tested, the substances absorbed from ultraviolet to infrared light are mainly melanin, water, hemoglobin, cell color change, etc. The absorptive capacity of different substances is different, and the absorptive coefficient of different substances in biological tissues is different. From the analysis of data, we can see that the absorption spectrum curve of water to light is very wide. It can be seen from the spectrum that water absorbs the infrared region most obviously[3]. But different tissues absorb the most light energy from visible light to infrared light, so the wavelength of light is about 532 nm, which can be used to simulate human tissues better in the next experiment.

3. Experimental design

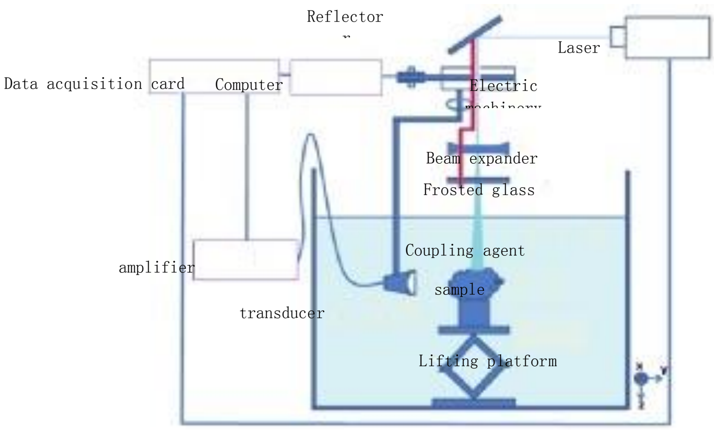


Fig. 1 Schematic diagram of experimental system design

According to the principle of the experimental system, the experimental objects and instruments are designed. The schematic diagram of the experimental design is shown in Figure 1. The main experimental instruments designed on the diagram are laser, rotary motor, rotary motor controller, amplifier, ultrasonic transducer, oscilloscope and computer. The working principle of the experiment design: laser emits laser, reflects through mirror, and then irradiates on the experimental sample or biological tissue through beam expander. Biological tissue expands because of absorbing laser energy, and produces ultrasound when biological tissue expands. This kind of ultrasound detects its signal through ultrasonic transducer, but the electric signal is weak at this time, and then passes through. Amplifier amplification, and then data acquisition through data acquisition card or oscilloscope. When the ultrasonic probe is in a position, data is collected once, through multiple rotations, multiple data acquisition at different locations, and then data is saved by computer. The computer not only serves as the data storage, but also as the control end of the rotary motor controller. Finally, the obtained data are combined with the imaging algorithm for image reconstruction[4].

After the system experiment design, combined with the experimental objects to be done, the factors are analyzed and the appropriate experimental equipment is selected. The relevant experimental instruments designed include: laser, stepping motor, motor controller, ultrasonic probe, amplifier, oscilloscope, computer, optical fiber (diameter 18mm), instrument support, photoacoustic imaging test bench, etc. to build the experimental system, as well as the phase. The experimental program system of the control system. In the process of debugging the experimental operating system, we need to constantly find the best experimental signal, then observe the signal graph displayed by the oscilloscope, then determine the position of the experimental object according to its waveform signal, and finally carry out the experimental research operation. Figure 2 shows the signal obtained by debugging the oscilloscope.

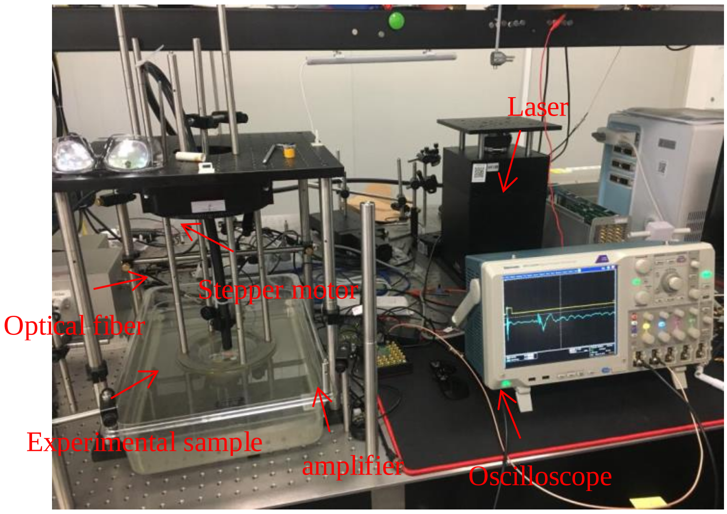


Fig. 2 Operational diagram of experimental design system

The algorithm of image reconstruction is the delay summation algorithm[5]: It mainly uses the ultrasonic transducer to detect the sound pressure signals of experimental samples and biological tissues. According to the distance difference between the location of transducer and the location where biological tissues need to be reconstructed, the amount of light absorbed by a certain point of biological tissues is inverted[6]. According to the distance between the ultrasonic transducer and the experimental point of biological tissue, this algorithm calculates the delay of the ultrasonic transmission to the ultrasonic transducer, and finally determines the intensity of the source when the biological tissue emits the acoustic wave. The formula is as follows:

$$A(r) = \frac{\sum_k w(k,r) p_k(r, t + T(k,r))}{\sum_k w(k,r)}$$

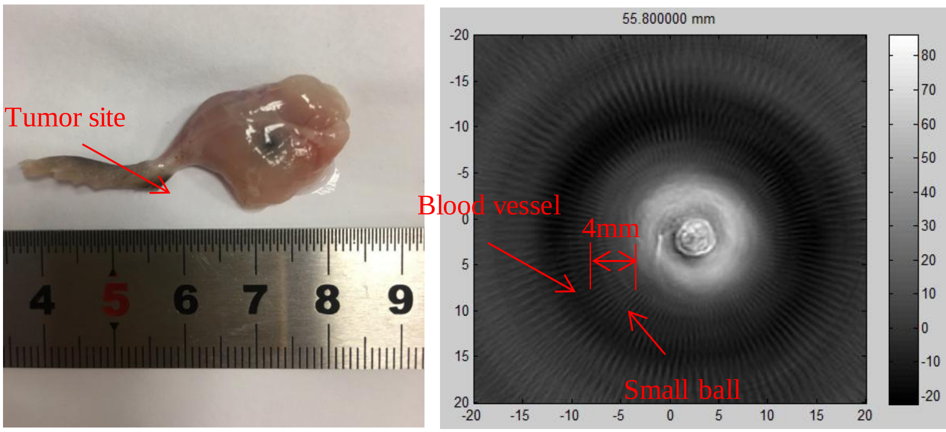
In the formula, r :the coordinate vectors in Cartesian coordinate system, t : the initial delay, the time of the ultrasonic transducer from the beginning to the biological tissue stimulated by laser irradiation, k :the ultrasonic transducer, $w(k,r)$:expressed as the weight, $T(k,r)$:the distance from the position r to the ultrasonic transducer k, p_k :the sequence of ultrasonic signals received by the ultrasonic transducer, $A(r)$ is the intensity of the absorbed light at the point.

4. Experimental operation and result analysis

According to the design and application scope of the experimental instrument, the whole experiment was further studied, and the experimental system was tested more authentically. The hind leg of mice was selected for experimental study. It was assumed that there were tumors in the hind leg muscle, but the naked eye observation was not enough to judge, so it was necessary to use the experimental instrument to detect [7]. A 3.95 mm diameter ball was inserted into the muscles of the hind legs of the mice as a tumor in the muscles of the thighs of the mice. The tumors in the muscles were then imaged by this experimental system. The color of the globule is black. It is made by a 3D printer. While the operation of the experimental object is completed, it can not be seen from the surface of the muscle of the leg. The tumors in the leg of the mouse are detected. The experimental results are shown in Fig. 3.

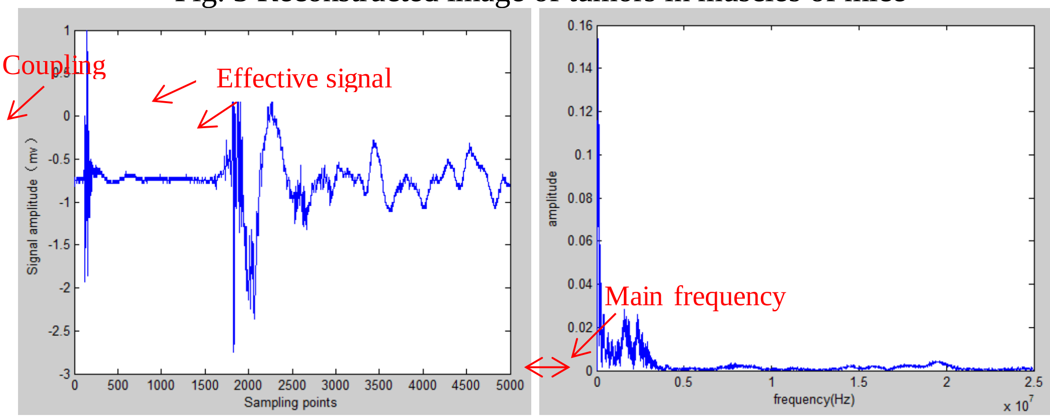
From the results of the experiment, we can see the reconstructed image. The diameter of the simulated tumour in the leg of mice is 3.95 mm. In the reconstructed image, we can see that the diameter of the tumour is about 4 mm. At the same time, we can see that there is a blood vessel in the muscle of mice beside the tumour. The blood vessel can be seen to be thin, but its location can be judged. From this, we can see the reliability of the experiment of detecting tumors in muscle tissue The experimental results further verify the accuracy of the experimental system and the experimental imaging algorithm.

The probe rotates to scan for a week and collects data three degrees apart. It needs to collect data at 120 locations. It can analyze the time-domain and frequency-domain maps at different locations. Fig. 4 is the time-domain and frequency-domain maps at the position of $\theta = 180^0$. The signal intensity of tumors in tissues is evident in time domain maps. In the frequency domain diagram, it can be seen that the main frequency concentration of the signal is in the range of 0.5MHz-3.5MHz, which is related to the characteristics of the muscle tissue of the mice and the material of simulating tumors printed in 3D.



(a) Leg tumor (b) Tumor reconstructed image

Fig. 3 Reconstructed image of tumors in muscles of mice



(a) θ=1800Time domain diagram (b) θ=1800 Frequency domain diagram

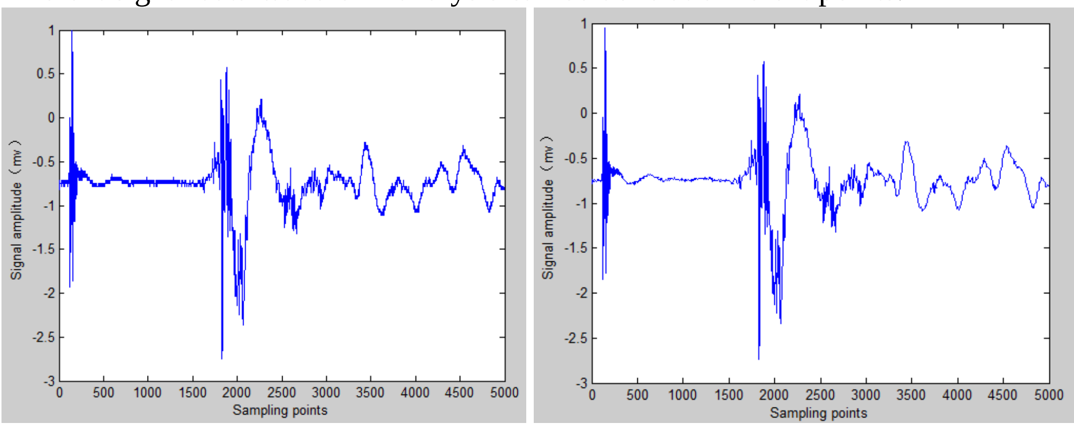
Fig. 4 θ=1800 Time-domain and Frequency-domain Diagrams of Location

From the above experimental results, the accuracy of the design of the experimental system is illustrated, which can be operated and implemented, and the results can be obtained. The rationality of the design of the experimental system of photoacoustic imaging is further illustrated and the requirements of the experiment are satisfied. Secondly, through the experimental results, the feasibility and accuracy of the imaging reconstruction algorithm are verified, which is a demonstration for the delay summation algorithm. However, from the experimental results, we can see that there are noise and artifacts in the image, the quality of reconstructed image is not high, and the clarity of reconstructed image is not high.

5. Improvement and improvement of experimental results

Referring to various references and books and other related information, the denoising method of wavelet threshold [8] and bilateral filtering [9] is adopted. The basic principle of wavelet threshold is that the difference of wavelet coefficients directly corresponds to the difference of signal characteristics. Some large wavelet coefficients include the characteristic information of most effective signals. The information of noise signals is distributed in all coefficients of wavelet, so it can be directly analyzed that the corresponding wavelet coefficients of effective signals are much larger than those of noise[10]. Therefore, we can set a threshold, the coefficient larger than this value is considered to be effective signal, the threshold coefficient smaller than this value is considered to be noise, the effective signal part of the coefficient is retained, the remaining coefficients are discarded, and then the denoised coefficients are sorted out, and then the coefficients are recombined according to the coefficients, and finally the results of data processing are obtained. Bilateral filtering is defined as the use of edge-preserving non-linear filtering method. This principle is the same as the principle of Gauss filtering, which uses partial weighted averaging as the main idea. It can exist synchronously in the geometric relationship of pixels and the similarity of gray levels. The combination of these two aspects enables bilateral filtering to remove noise adequately and smoothly in processing objects. Sound[11], and does not blur the edge information of the image.

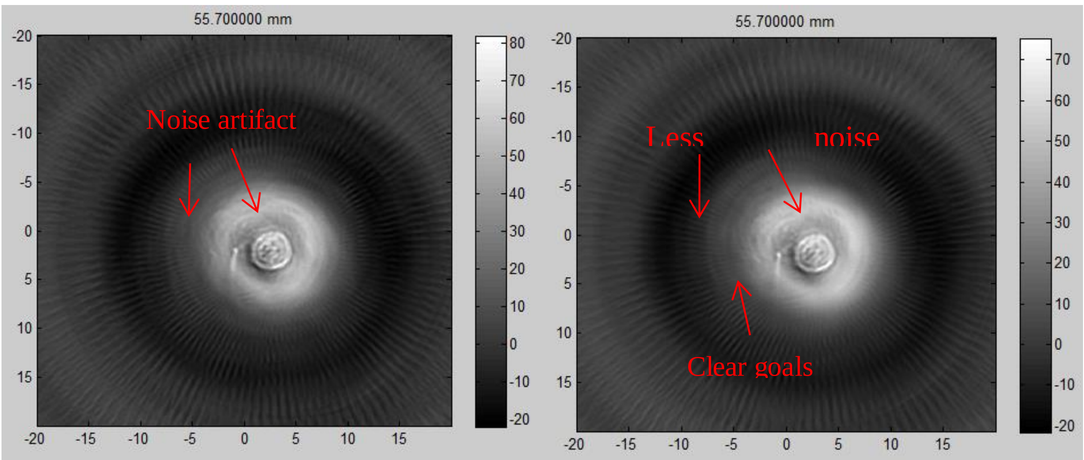
During the whole experiment, the probe rotates to collect data of 120 locations in a week, and the data collected at each location is 5000. Fig. 5 is the result of the data collected at the position of $\theta=180^0$. Different signal data waveform analysis can be done at different points.



(a) $\theta=180^0$ Data Signal Acquisition at Position (b) $\theta=180^0$ Data Signal after Location Processing

Fig. 5 $\theta=180^0$ Contrast Chart of Data Processing before and after Acquisition in Position Time

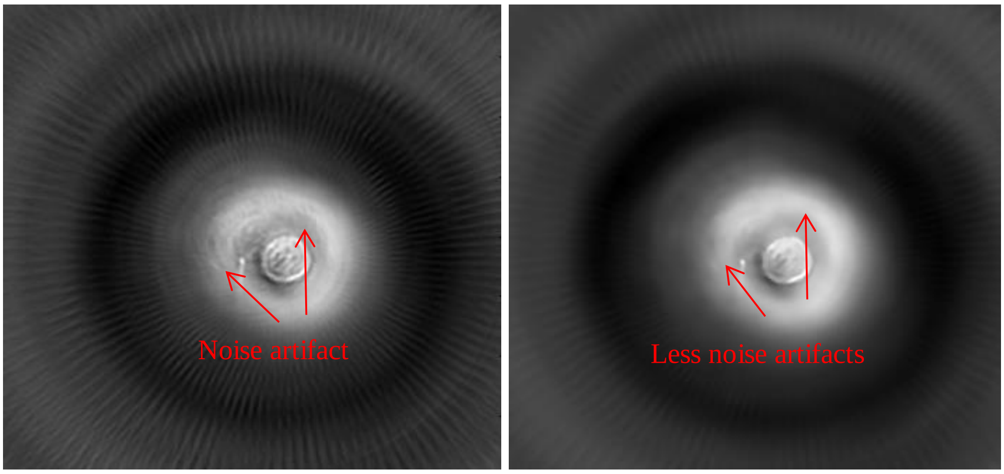
After the original data is processed by wavelet threshold, image reconstruction is performed. Fig. 6 is the contrast result of reconstructed image before and after data processing. Before data processing, it can be seen that there are black ripples around the image. This is the artifact of the image [12]. On another picture, it can be seen that the result after data processing is better than that before data processing. There are less artifacts, less noise and small lines in other parts of the image, and the reconstructed object is clearer than that in other parts of the image, so the result of improving the image quality is achieved.



(a) Image before data processing (b) Image after Data Processing

Fig. 6 Image contrast before and after wavelet threshold processing

According to the results of image reconstruction, the quality of image needs to be further improved. The noise of image is still serious and the clarity is not high. So the method of bilateral filtering denoising is used to denoise [13.14]. The contrast, clarity and quality of image can be changed greatly, so that the result of photoacoustic imaging can be carried out. A good judgment and analysis.



(a)Image Processed by Wavelet Threshold (b) Image processed by bilateral filtering

Fig. 6 Contrast Charts of Bilateral Filtering Algorithms before and after Processing

When denoising and removing artifacts in muscle tissue reconstruction imaging, we can see that the size and shape of tumors, other surrounding conditions, and nearby blood vessels are more clearly displayed, and the features are more obvious, which can be better distinguished and distinguished. Through the processing of this algorithm, the features can be judged more clearly, so that the final image quality can reach the highest.

6. Conclusion

Firstly, through the preliminary imaging of the experiment, we can see that the reliability and accuracy of the experimental platform system design are verified. At the same time, we can also see the reliability of the delay summation algorithm used in image reconstruction. Finally, according to the processing results of the experiment, the final clarity and quality of the image have been significantly improved and improved, the problems arising from the experiment have been solved, and the accuracy and accuracy of the experiment have been improved. Therefore, the detection and judgment of the experimental objects have been greatly improved and improved.

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