

Real-time photoacoustic tomography using linear array probe and detection of line structure using Hough transform¹

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Abstract. A real-time photoacoustic tomography (PAT) system is developed using a linear array probe and phantom images are acquired with a pattern of line structure. Moreover, it is attempted to detect line structures from the acquired images by Hough transform. This effort leads to the measurement of a process of magenta passing through a tube and acquisition of images at a speed of about 2 frame/sec. Besides, it is confirmed that the Hough transform applied on the acquired PAT images has the detection rate of about 50% for delineating a line structure.

Keywords: Photoacoustic image, back projection algorithm, ultrasonic imaging, Hough transform, line structure

1. Introduction

Photoacoustic tomography (PAT) is an imaging technique based on the photoacoustic source distribution. When electromagnetic waves such as radio waves are applied onto the biological tissues, a part of the energy will be absorbed by the tissues and then transformed to heat which leads to thermo-elastic expansion. Then, ultrasonic waves with wide band frequency, termed as photoacoustic, are generated and they would be measured on the surface of the biological tissue by an ultrasonic transducer and reconstructed as images [1-4]. One special feature of the PAT is that it has a high optical contrast ratio as an optical visual technique such as optical coherence tomography (OCT) and high space resolution power as an ultrasonic imaging technology. Besides, since the intensity of photoacoustic is varied over optical absorption rate of biological tissue, it is possible to visualize biological changes of the biological tissues. Therefore, the PAT is widely adopted in various

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diagnostic areas [5-7]. In addition, real-time PAT techniques have been studied to acquire functional images of biological tissues.

The PAT reconstructs images with photoacoustic signals measured at various directions, so the real-time photoacoustic imaging system uses an array transducer embedded with a number of ultra-sound transducers. However, it is difficult to obtain images of good quality because conventional linear array probe used in ultrasound devices has a limited angular view. Therefore, the photoacoustic imaging system which overcomes the limitation with a 2D array probe has been proposed [8] and studied in terms of real-time photoacoustic imaging techniques [9, 10].

The limitations of the system, such as limited intensity, size of a detector in apparatus and in reconstruction algorithm can cause noise in the image. These noises would cause the problem in the process of interpretation, so it is critical to remove noises from images. Moock, et al. [11] proposed to reconstruct an image after filtering of the acquired photoacoustic signal information and Zhang, et al. [12] improved the images quality by applying the back-projection algorithm and then the anisotropic diffusion method for the reconstruction of photoacoustic images. Oruganti, et al. [13] emphasized the blood vessel structure by applying the vessel filtering technique to the blood vessel structure image, which is acquired by the 3D photoacoustic imaging technique. Nevertheless, there are few studies on the removal of noise for photoacoustic images.

In this study, for the initial research on the development of the real-time PAT system, a real-time PAT image acquisition device is developed using a linear array probe for ultrasonic device and phantom images are acquired to include a line structure. Moreover, a line structure is detected by applying the Hough transform [14, 15] onto the acquired images and line structure of PAT images is emphasized by applying different filtering techniques to the detected line structure area and the rest area, respectively.

2. Materials and methods

2.1. The proposed photoacoustic image acquisition system

Photoacoustic signal must be measured in real time for the acquisition of PAT images. In addition, emission of light source, acquisition of photoacoustic signal and transformation of images must be made concurrently. In order to achieve these mandatory conditions, PXI platform based data acquisition (DAQ) device is employed, which is equipped with 64 analog input channels as well as 50 MHz sampling frequency and 12 bit resolution power. Besides, it can communicate with a PC with a speed of 192 Mb/s through direct memory access (DMA). A laser trigger controller is developed for the transmission of trigger signals representing the light emission time and a linear array probe (L14-5/38, Ultrasonix) is used, which is composed of 128 transducers with the central frequency of 5 MHz. Moreover, for the amplification and filtering of the measured photoacoustic signals, a preamplifier with 64 channels and 40 dB gain and 5 MHz band is produced and equipped at the front side of DAQ. The acquired image is 488×400 pixels with $0.08 \text{ mm} \times 0.08 \text{ mm}$ resolution per pixel. Figure 1 shows the diagram of the real-time PAT image acquisition system.

Back projection algorithm is employed for the reconstruction of images based on the data acquired from the PAT image acquisition system. Back projection algorithm is to back project the transmission of photoacoustic over time to reconstruct the initial photoacoustic distribution, and it is widely used for photoacoustic imaging. Eqs. (1) and (2) explain the back projection algorithm [16].

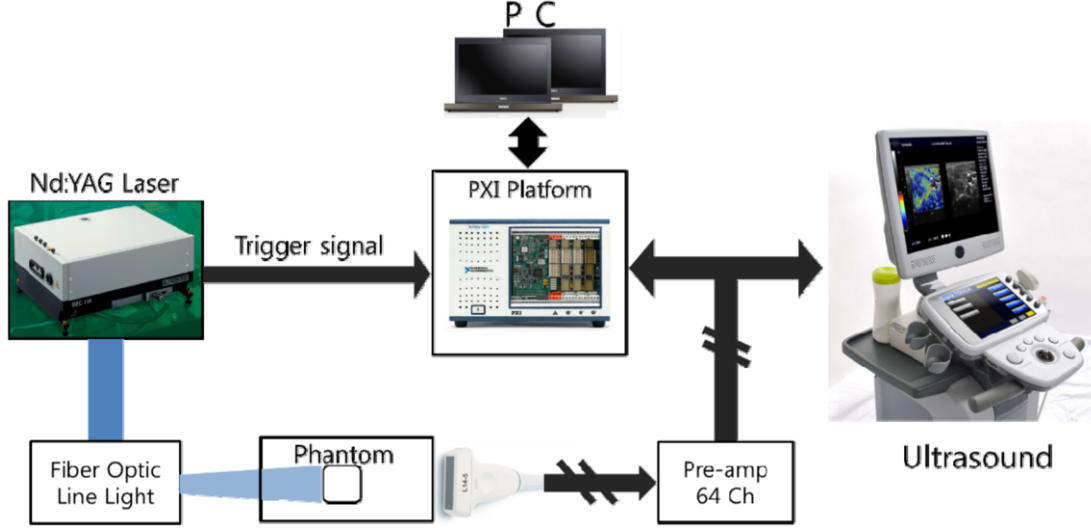


Fig. 1. Diagram of the real-time PAT image acquisition system.

$$p_0(\vec{r}) = \int_{\Omega_0} \frac{d\Omega_0}{\Omega_0} [2p(\vec{r}_0, v_s t)], \quad t = \left| \vec{r} - \frac{\vec{r}_0}{v_s} \right| \quad (1)$$

$$d\Omega_0 = \frac{dS_0}{|\vec{r} - \vec{r}_0|^2} \cdot \frac{\hat{n}_0^s \cdot (\vec{r} - \vec{r}_0)}{|\vec{r} - \vec{r}_0|} \quad (2)$$

Where p_0 represents the initial photoacoustic signal, \vec{r} represents a vector for a coordinate of the desired image, \vec{r}_0 represents a coordinate of the measurement of a transducer, v_s represents the speed of ultrasonic waves, $p(\vec{r}_0, v_s t)$ represents the measured photoacoustic signals, and Ω_0 represents a solid angle in the \vec{r} direction of the desired image on the surface.

2.2. Modified Hough transform

In the present research, the Hough transform is employed to detect a line structure from the acquired PAT images. Hough transform is a technique to detect a straight line from images. In an image, pixels in the cartesian coordinate space are expressed to be curved lines in the polar coordinates space. Besides, pixels on the same straight line in the cartesian coordinate space are likely to have intersection points in the polar coordinates space. Hough transform conducts the mapping of pixels of an image from the cartesian coordinate space to the polar coordinates space and detects straight lines by detecting the cross points with the largest accumulation number. Eq. (3) is the coordinate transformation for the Hough transform.

$$\rho = x \cdot \cos \theta + y \cdot \sin \theta \quad (3)$$

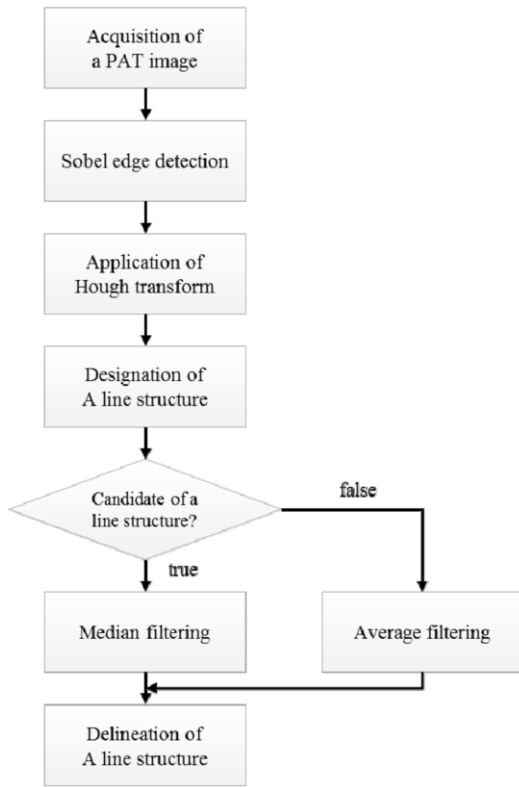


Fig. 2. A flow chart of the line structure detection.

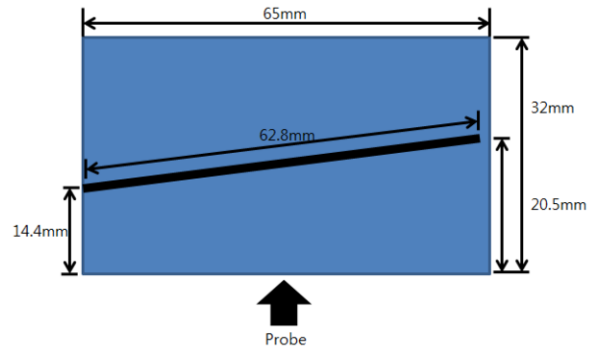


Fig. 3. A phantom for the acquisition of PAT images.

Where, x and y represent a position in the cartesian coordinate space, while ρ and θ represent a position in the polar coordinate space.

To emphasize the line structure detected by the Hough transform, different filtering techniques are employed for the line structure area and the structure area without lines. Figure 2 shows a flow chart of the detection of the line structures.

3. Result and discussion

3.1. PAT images of a phantom

Images of the produced phantom as shown in Figure 3 are acquired by the real-time PAT image acquisition device. The phantom is made of gelatin (protein, 84–90%; water, 8–12%) to create an environment similar to that of biological tissues in a $65 \times 32 \times 18$ mm hexahedron shape. Magenta is slowly injected into a tube inside the phantom and images of magenta passing through the tube are obtained. Light source is Nd:YAG laser (Meditech, Eraser-k) with a wavelength of 532 nm and the emission speed of the light source is set to be 2Hz. In addition, the fiber optic line light (NT57-019, Edmund Optics) is used to emit the light source because the measurement range of the phantom is much larger than that of the beam of the light source. Figure 4 shows images of the phantom acquired by the developed PAT image acquisition device.

The obtained image has the size of 570 x 300 pixel with the resolution power of 0.07 mm x .07 mm

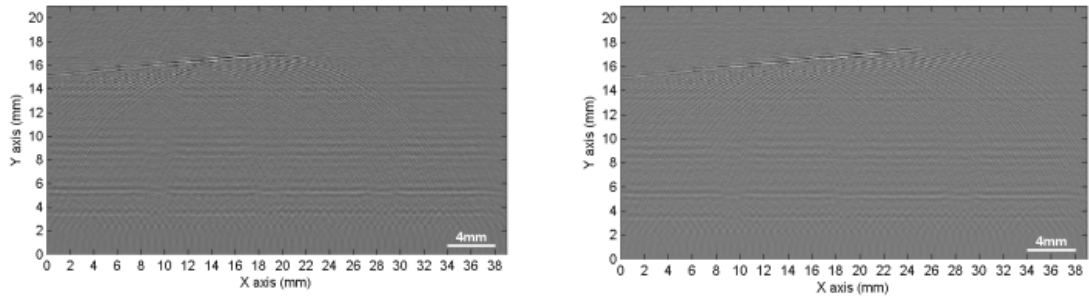


Fig. 4. PAT images of magenta dye flow through transparent polymer tube.

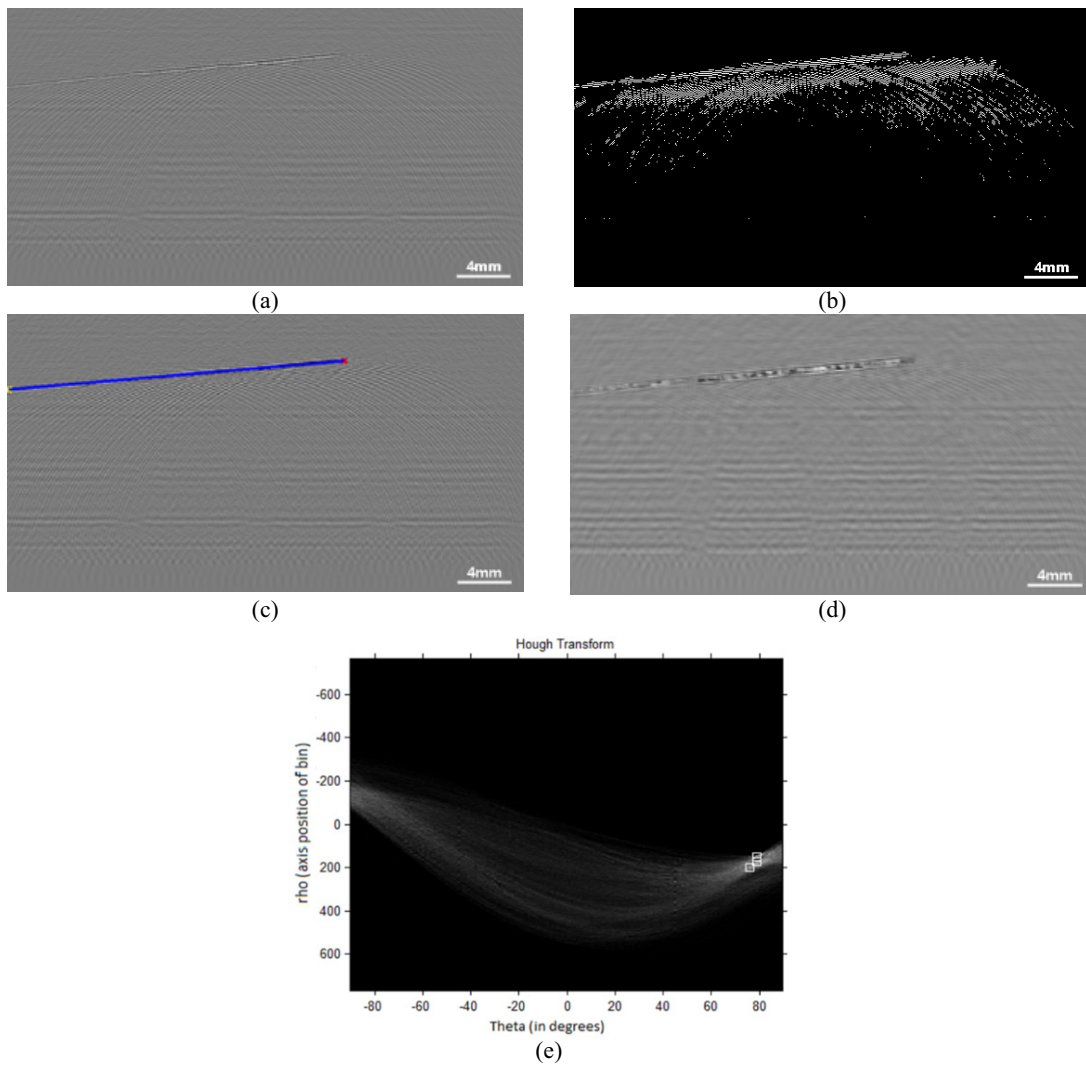


Fig. 5. Result of line structure detection (a) Original image. (b) Result of edge detection by Sobel operator. (c) Result of image with Hough transform. (d) Result of image filtering. (e) Graph of Hough transform in polar coordinate space.

Table 1
Result of line structure detection from PAT images

Number of image	Result	Number of image	Result
1	False	9	False
2	False	10	False
3	False	11	True
4	False	12	True
5	True	13	True
6	True	14	True
7	False	15	False

per pixel and the frame speed is 2 frame/sec since the emission speed of the light source is set to be 2Hz. However, it could be checked that the thickness of the tube image found on the acquired image is less than 1 mm. It is due to the fact that the light source emanated by the fiber optic line light is not distributed over the tube and only one side of the tube is shown in the image.

3.2. Detection of a line structure

Hough transform is employed to detect a polymer tube which is expressed as a line structure in the PAT image obtained by the phantom. Figure 5 shows line structures detected from the obtained PAT images, varying over line structure detection method.

Figure 5(b) is an essential stage for the application of the Hough transform and shows the edge map generated by Sobel edge detection technique [17]. Besides, a line structure assignment method in Figure 5(d) is a process of expanding the area for straight lines detected from the Hough transform, and a section for straight lines with the thickness of 5 pixels is set with the bresenham algorithm [18, 19]. Figure 5(e) shows the filtering executed by employing the median filter in the straight line section to enhance the quality of an image and the average filter for the rest sections to remove noises of the image. It results in the PAT image with clear line structures. It shows the line structure detection for 15 PAT images obtained by Figure 4. Table 1 shows the results of the detection of line structure from each image.

The line structure detection rate is about 50% in PAT images except for the first image which shows an image before injecting magenta. The reason that line structures could not be detected from the obtained PAT images might be as follows. First, the detection algorithm is set to detect only straight lines longer than the specific length, thus the line structures that fail to meet this criteria will not be detected. Second, when noises from the obtained PAT image are represented in straight lines, noises could be detected as a line structure. Consequently, it would be necessary to change parameters of the algorithm and to enhance the algorithm so that it could select the optimum straight line among various detectable straight lines.

In order to measure the filtering results in terms of quantity, the averages of Root Mean Square Error (RMSE), Peak Signal to Noise Ratio (PSNR), and Mean Absolute Error (MAE) are calculated. Table 2 shows the quantitative data regarding the filtering results of the PAT images.

4. Conclusion

Table 2
Comparison of the Quantitative result of filtering

	Median filtering	Proposed filtering
RMSE	10.923	10.899
PSNR(dB)	27.379	27.398
MAE	7.149	7.238

Hence, ①in terms of applications with the interpretation of PAT images, ②the detection of the blood vessels is quite important especially to diagnose the condition of the vessel. However, ③the contrast sensitivity is normally low between the vessel and the surrounding organs. Hence, a real-time PAT image acquisition device is developed using a linear array probe for ultrasonic device and images of phantom are acquired to include a line structure. Moreover, it is attempted to detect line structures from the acquired images by the Hough transform. This effort leads to the measurement of a process of magenta passing through a tube and it is confirmed that the Hough transform applied on the acquired PAT images has a proper line structure rate. However, the speed of the developed PAT image acquisition device is low and there could be noises due to the limited measurement range of a linear array probe. Also due to the inherent characteristics of the low signal to noise ratio in a PAT image, the conventional line detection algorithm such as combining an edge detection operator and connecting the edge components would work very poorly. The only possible alternative is to detect the line components in the noisy PAT image by using Hough transform and this transform detects the linear structures with an accuracy of 50 % in which the performance index will be improved as a new method is found to increase the signal to noise ratio of a PAT image in the future efforts. Therefore, the future study should focus on raising the image acquisition speed by enhancing the image reconstruction algorithm of the developed system as well as the detection rate by improving the line structure detection algorithm.

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