A NSRS Detection Method for Ablation Needles in CT Images

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ABSTRACT

In CT image-guided interventional surgery, the rapid and accurate positioning of ablation needle plays a key role in the smooth operation. There is no universal and effective method for line segment detection, especially for the accurate extraction of feature points in image processing. Aiming at the problem of detecting and locating the ablation needle and its tip in CT image-guided interventional surgery, a method of NSRS line segment detection based on Randon transform and sliding window method is proposed. Experiments show that the method can accurately extract the end coordinates of the needle and accurately locate the ablation needle in CT image.

KEYWORDS

CT image-Guided Interventional Surgery, Ablation Needle, Randon Transform, Sliding Window Method, NSRS Line Segment Detection Method.

INTRODUCTION

In recent decades, with the development of various advanced medical imaging technologies, such as magnetic resonance technology (MRI), ultrasonic technology (US), computed tomography (CT), etc., it has been widely used in the important links

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of surgical diagnosis, surgical treatment, rehabilitation detection and telemedicine[1,2]. Image processing and analysis has become one of the most rapid and effective fields of medical technology. The combination of digital image processing technology with computer and medical image processing, processing, auxiliary, diagnosis and guidance is more and more favored by many countries.

Image-guided interventional therapy or minimally invasive imaging equipment enables doctors to accurately locate and deeply observe the lesions, and use vascular catheter technology or percutaneous puncture instruments to diagnose and treat the lesions of internal organs. Due to the small damage and rapid recovery, this treatment method has become more and more popular, and some countries have listed the research of image-guided minimally invasive treatment into the strategic height of national development. In CT image-guided interventional surgery, rapid and accurate positioning of the ablation needle plays an important role in the smooth operation, in particular the design of surgical navigation system, such as biopsy, interventional surgery, the process through one of the most important tasks is to get patients, cross section image guided needle inserted into the right patient[3].

Although MRI and US have been used for needle guidance, CT images provide a higher density resolution and clearer imaging method to form two-dimensional sections without interference of structures beyond the layers.

At present, the methods of needle detection in medical images are mainly divided into two categories: hardware-based and software-based methods. In hardware-based methods, the ability to localize the needle is improved by using external systems to track the needle in the CT image. Rashed et al.[4] introduced a method of needle detection interventional pain management surgery using clinical C-arm scanner. Najafi et al.[5] proposed to estimate the position of the needle in the image by using the camera mounted on the ultrasonic probe. Daoud et al.[6] introduced a novel needle detection algorithm based on the unique needle reflection pattern of circular ultrasound waves. Software-based methods include: Xie Zhinan et al.[7] proposed a fast segmentation method of puncture needles in CT image guidance, and used FFT filtering and the improved Ostu method to segment the needles, which is simple to operate but lacking in accurate positioning of the needle tip. They also proposed a puncture needle detection and positioning method combining gradient edge detection algorithm and FFT[8], which can filter and enhance images, but still need to be improved when inserting needles into complex positions. Daoud et al.[9] proposed an accurate needle location method for ultrasound images. This method is based on the characteristics of ultrasound images for needle detection, which can be used for reference in CT images.

In order to detect and locate the needle and its tip in CT images in interventional surgery, this paper proposes a NSRS line segment detection method, which first uses
the non-local mean method (NLM) to smooth the image, and then uses the Sobel operator edge detection. The Randon transform detects the positioning needle axis, and finally selects the region of interest (ROI) where the needle shaft is located in combination with the sliding window method to detect the positioning needle tip.

The remainder of the paper is organized as follows: Section II describes the proposed needle localization method. The results and conclusion are provided in Sections III and IV, respectively.

MATERIALS AND METHODS

The proposed needle localization algorithm consists of five phases: smooth noise reduction, edge detection, needle axis detection and localization, ROI recognition, needle tip localization. These five phases are described in the following subsections.

SMOOTH NOISE REDUCTION

In this phase, in order to reduce the effect of metal artifact noise in CT images, the first step is to denoise the image. The non-local mean filtering algorithm extracts the structure of the image based on the correlation between the target pixel and the surrounding pixel, while filtering the noise, it retains the image details[10]. The principle is as follows:

$$NLM(v(m)) = \sum_{n \in I} \frac{1}{C(m)} \exp\left(-\frac{\|v(m) - v(n)\|_2^2}{h^2}\right) v(n)$$

(1)

In Equation(1), $v(m)$ is a rectangular neighborhood centered on the pixel $m$, and $v(n)$ is another rectangular neighborhood centered on the pixel $n$. $I$ represents the entire image space and $n \in I$. $C(m)$ is the normalized parameter. $h$ is the smooth parameter of the control function. $\|v(m) - v(n)\|_2^2$ is the Gaussian weighted Euclidean distance and $\alpha$ is the Gaussian nuclear standard deviation. After NLM, the image quality is improved obviously. Figure 1 (a) and (b) show non-denoised CT images and smoothed denoised CT images respectively. In addition, in Figure 1 (c), the axis of ablation needle is represented by blue arrow and the needle tip by red arrow.
EDGE DETECTION

Using Sobel edge detection method, the Sobel operator takes into account the neighborhood information. After weighted smoothing, the image is processed by differential calculation, which has a certain ability to suppress noise. The effect of edge location and detection is excellent[11]. The sobel operator is used to detect the edge of medical image. Firstly, the image is convoluted by the horizontal operator and the vertical operator respectively, and the two matrices are obtained as follows:

\[
\begin{bmatrix}
-1 & -2 & 1 \\
0 & 0 & 0 \\
1 & 2 & 1
\end{bmatrix}
\quad \begin{bmatrix}
-1 & 0 & 1 \\
-2 & 0 & 2 \\
-1 & 0 & 1
\end{bmatrix}
\]

Then the Sobel gradient operator does the weighted average and then differentiated. Finally, the gradient is calculated. The calculation formula is:

\[
G = \sqrt{G_x^2 + G_y^2}
\]  

In Equation (2), \(G_m\) is the convolution in the x direction of the original image and \(G_n\) is the convolution in the y direction of the original image. The results of CT image edge detection are shown in Figure. 1 (d).

NEEDLE AXIS LOCALIZATION

After edge detection is completed, the CT image is Randon transformed to extract the straight line, where the needle axis is located. The Randon transform is a line integral transform, which can be directly used to detect the linear components in the image[12]. For the purpose of locating the needle axis accurately, the method of combination threshold plus Randon transform is used in this paper. The principle of Randon transformation is as follows:

\[
Randon(P, \theta) = \int_{-\infty}^{\infty} f(m,n) \delta(P - m \cos \theta - n \sin \theta) dl
\]  

(3)
Equation (3) refers to a line in space, which is corresponding to each point in space, and representing the Delta function. Figure 1 (d) shows the straight line of the needle axis of the CT image.

**ROI RECOGNITION**

After extracting the straight line of the needle axis, the region of interest (ROI) of the parallelogram region, where the straight line is located is identified. On the one hand, the interference of other tissues and organs is removed, on the other hand, preparations are made for the next step of using sliding window method to detect and locate the needle tip. The ROI recognition of CT images is shown in Figure 1 (e).

**NEEDLE TIP LOCALIZATION**

Once the needle axis has been accurately positioned, the sliding window method can be used to determine the position of the tip along the needle axis. In particular, the size of the window selected at the needle entrance is 100×64 sliding to improve accuracy. An quantitative needle metric is calculated at the window position, in which the window moves along the needle axis until all pixels along the axis are covered by the sliding window. The high value of quantitative needle measurement indicates that the needle exists in the window position, while the low value indicates that the needle does not exist in the window position. Since the tip represents the end point of the needle, the position of the tip is considered to be the break point between the high and low values of the quantitative needle measurement. Therefore, the needle point is located along the axis of the needle, which maximizes the size of the spatial derivative of the quantitative needle measurement. Figure 1(f) and (g) show the tip of sliding window estimation respectively.

![Figure 1](image)

Figure 1. (a) and (b) show non-denoised CT images and smoothed denoised CT images respectively.
Figure 1. (c), the axis of ablation needle is represented by blue arrow and the needle tip by red arrow; Fig. 1 (d) the straight line of the needle axis of the CT image.

Figure 1. (e) the ROI recognition of CT images; Fig. 1 (f) and (g) the tip of sliding window estimation respectively Fig. 1 (f) and (g) show the tip of sliding window estimation respectively. (h) Accurate estimation of the required tip of the red circle indication on CT images is achieved by sliding.

TABLE I. COMPARISON OF MORPHOLOGICAL INFORMATION BETWEEN NEEDLES IN IMAGES TO BE DETECTED AND NEEDLES IN TEST RESULTS.

| Sequence number | Parameter Description | Length(mm) | Angle(°) | The tip coordinates of needles(x, y) | The tail coordinates of the needle(x,y) |
|-----------------|-----------------------|------------|----------|-------------------------------------|--------------------------------------|
| Fig. 1 (a)      |                       | 23.40      | 68.94    | (34.20,35.70)                       | (26.70,14.40)                        |
| Fig. 1 (h)      |                       | 23.10      | 69.44    | (34.50,35.40)                       | (26.40,14.40)                        |
| Fig. 2 (a)      |                       | 30.00      | 90.56    | (30.90,37.50)                       | (31.50,6.00)                         |
| Fig. 2 (b)      |                       | 29.10      | 91.18    | (30.90,36.60)                       | (31.50,7.20)                         |
| Fig. 2 (c)      |                       | 23.20      | 5.93     | (33.60,38.40)                       | (11.10,40.80)                        |
| Fig. 2 (d)      |                       | 22.90      | 6.70     | (33.30,38.40)                       | (10.20,41.10)                        |
| Fig. 2 (e)      |                       | 22.14      | 7.43     | (34.80,43.20)                       | (14.70,40.50)                        |
| Fig. 2 (f)      |                       | 22.40      | 6.25     | (35.40,43.20)                       | (14.10,40.80)                        |
Figure 1 (a) - (h) shows the process of detecting and locating CT images of a liver section with ablation needles. (a) The actual detected image to be detected. (b) The NLM method is used to set the corresponding smoothing parameter h to get the image. (c) The meaning represented by red and blue arrows. (d) The detection map obtained by Sobel edge detection method, in which the combined threshold and Randon transform are used to accurately estimate the needle axis, and a blue line is used to represent the needle axis. (e) Represents cutting the CT image into a parallelogram ROI so that the ROI has a central axis matching the initial estimated needle axis, i.e. the width is equal to three times the diameter of the needle, and the length spans the CT image. (f) A sliding window method is used to find the tail of the needle in the ROI region. (g) A sliding window method is used to find the tip of the ROI region. (h) Accurate estimation of the required tip of the red circle indication on CT images is achieved by sliding.

RESULTS

In order to verify the validity and accuracy of the proposed method, this section analyzes and compares the above experimental results, in which the morphological information of the needle and the detection result needle in the image to be detected is extracted, including length, angle and coordinates. The actual liver CT images Figure 1 (a) and test results Figure 1 (h), ovarian CT images Figure 2 (a) and test results Figure 2 (b), brain CT images Figure 2 (c) and test results Figure2 (d), liver CT images Figure 2 (e) and test results Figure 2 (f) are shown in Table I.
Figure 2 (a) - (f) shows the pinpoint detection and location maps of two CT images respectively. (a) The graph shows the CT images of an ovary with ablation needle. (b) The graph shows the tip location of ovarian ablation needle after NLM smoothing, Sobel edge detection, Randon transform, ROI interception and sliding window iteration. (c) The graph shows the CT images of a brain section with ablation needle. (d) The graph shows the final location of the brain ablation needle after NLM smoothing, Sobel edge detection, Randon transform, ROI interception and sliding window iteration. (e) The graph shows the CT images of a liver section with ablation needle. (f) The graph shows the needle tip location of liver ablation needle after NLM smoothing, Sobel edge detection, Randon transform, ROI interception and sliding window iteration.

CONCLUSION

CT images provide an effective and clear way to guide needle insertion interventions, such as biopsy and interventional surgery. In this study, a new NSRS model is proposed to accurately locate the pins and tips in CT images. The method adopts non-local mean method (NLM) to smooth image, Sobel operator edge detection, Randon transformation and combination threshold detection to locate the needle, and finally selects the area of interest (ROI) where the needle axis is located and combines with the sliding window method to detect and locate the needle tip. The experimental results show that the method performs well in "needle tip" and "needle tail" coordinates.

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