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Method for Location of Puncture Point Guided by Digital Mammography Image*

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Abstract—**The main purpose of this study was to develop a method that can optimize the algorithm for puncture point calculation, and therefore improve the accuracy of X-ray guided breast biopsy. The proposed method is: first, select two guiding points; then, use the guiding points to construct X-ray cone-beams, so the joining section of the cone-beams can be used to determine the puncture target point. The method was verified by a phantom emulation, in which the calculated target-points were all found within the central part of the target lesion, and far away from the boarder of the lesion (change the x-ray tube angle by 15° would only cause a slight deviation no more than 1.4 mm), the accuracy is enough to fulfill the needs of biopsy operation. This study also found out that, the shorter the distance between the guiding point and the center of the lesion's project, the nearer the calculated biopsy-point will be to the actual lesion center.**

I. Introduction

To prevent breast cancer, if micro lesions (less than 10mm in diameter) [1][5][6]can be detected at the early stage, patients could have better remedy and longer life expectance. According to recent studies, if micro lesions smaller than 10mm could be detected, patients' lives could be prolonged 5-10 years [12][13][15]. Usually, biopsy puncture or stereotactic biopsy are used to detect whether micro breast lesions are malignant or not in clinical practices [2][4][5][6].

There are three ways to guide the breast biopsy, such as MRI-guided, Ultrasound-guided, mammography-guided. The expense would be too much for MRI-guided breast biopsy, Ultrasound- guided breast biopsy nearly can't show micro-calcifications. Mammography-guided is the common way to perform breast biopsy. It is necessary to accurately find the ordinates for the puncture point [7][8][9], so as to guide the biopsy operation. However, there are deviations for the existing method with Mammography-guided, sometimes up to 2.5mm deviation from the target lesion center, or even the puncture point was located outside of the lesion. Moreover, it is especially difficult to locate micro lesions (smaller than 10 mm in diameter), if the puncture point is too near to the targeted-lesion's edge, the sampled tissue amount would not be enough to make a correct diagnose [13].

Based on the X-ray breast imaging system, this study presents a new method called X-ray cone-beam approach. If doctor can't judge some areas whether malignant or not in the breast image, we would find the targeted area in the breast image and calculate a puncture point to breast biopsy. The method suggests should be used in order to more accurately calculate the puncture point. This method is tested by Anke ASR-4000 digital mammography system. The result indicated that x-ray cone-beam approach is superior to other existing methods, it is based on a comprehensive theory, it has more accurate location ability, and a quicker calculation process.

In this study, firstly we proposed the mathematical model and a theoretical study of the X-ray cone-beam approach. Then we also verified the method by an experiment and analyzed the results.

II. Mathematical and Theoretical Derivation

A. Process of Locating Puncture Point

This study developed an improved method for locating puncture point based on X-ray mammography. To guarantee that the puncture point is centered inside the targeted lesion and that enough tissue can be gathered for biopsy. Two images are used in this study, to locate a single puncture point.

Because one pixel point on the X-ray image is a superposition of several spatial points; it is not possible to match spatial points via reference pixel-points on two different X-ray mammography images; based on this consideration, the study proposed that the lesion-center used be as the characteristic point, to guide matching and positioning.

As breast lesions are asymmetric; the lesion center on X-ray image may not be the exact projection of the real lesion-center. Therefore, in previous practices, only selecting and matching characteristic puncture points cannot provide a highly accurate diagnosis.

Two cone-beams that projected from two different tube angles would form the conjoining areas for lesion projections. The targeted lesion can be determined in the conjoining areas. If the common area can be found, the expected puncture point would be located in the center of the area.

B. Mathematical Model

With X-ray tube projecting from two different angles, we can acquire two images on the detector. Lesion-pairing (projections of lesion on the two images) can be found to reconstruct X-ray beam-cone. We select a point as GPT

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(Guiding-Point) from each of the two lesion-images. Inside a lesion-image, we draw a circle as GDC (Guiding-Circle), with guiding-point as its center. We also define x-ray source corresponding to the lesion-images DPS (Direct-Projection Source), the cone-beam is then formed by GDC and DPS as a Guiding-Cone, the shared space between two Guiding cones is defined as GDD (Guiding-Solid); then another plane is acquired by cutting the GDD with a plane parallel to the detector, it is named GPR (Guiding-Plane Area), the circles defining the GPR is named as SGDC (Section guiding circle).

The bottom part of the Guiding-Cone should be inside the lesion-image; thus the GDD should be included within the breast lesion. Then, a point inside the GDD which is far from its boarders can be considered as a feasible puncture point; and it should, in this case, provide enough lesion-tissue for diagnosis.

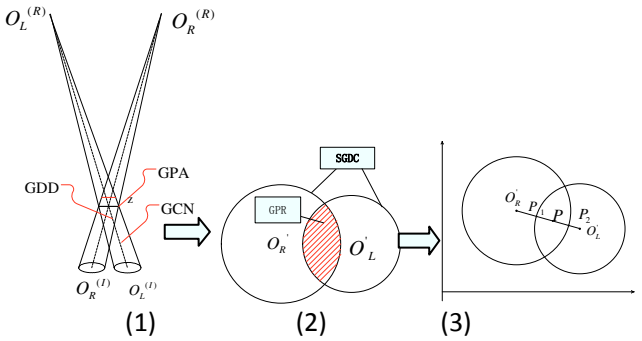

Figure 1.Model of breast biopsy: (1) shows the intersection of GCNs (guiding-cone), the common part of two GCNs is GDD, then acquiring GPR. (2) shows GPR and GCCs observed from z-positive. (3) shows SGDCs, ***P*** for puncture point, $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ for the intersection point between line $\boldsymbol{O_RO_L}$ and two circles.

C. *Theoretical deduction*

To establish the relationship of spatial coordinates and image coordinates, we transform GDC's coordinates on the image into GDC's coordinates on the detector. The GDC formed in the detector's coordinate system is thus called 'detector GDC'.

When X-ray tube projected from two different angles to ***Z***-axis, the two apexes (light source) are hereby named as $O^{(R)}{}_L(x_L^{(R)}, y_L^{(R)}, z_L^{(R)})$, $O^{(R)}{}_R(x_R^{(R)}, y_R^{(R)}, z_R^{(R)})$. The centers of the two 'detector GDCs' are named as $O_L^{(I)}(x_L^{(I)}, y_L^{(I)}, z_L^{(I)}), O_R^{(I)}(x_R^{(I)}, y_R^{(I)}, z_R^{(I)})$ radiuses of GDCs are $r_L^{(I)}$ and $r_R^{(I)}$. These factors can be constructed into a set of functions as follow:

$$\frac{r_L'}{r^{(I)}{}_L} = \frac{z_L^{(R)} - z_L'}{z_L^{(R)} - z^{(I)}{}_L} \qquad (1)$$

$$\frac{r_R'}{r^{(I)}{}_R} = \frac{z_R^{(R)} - z_R'}{z_R^{(R)} - z^{(I)}{}_R} \qquad (2)$$

The center-points of spatial GDCs are written as: $O_R'(x_R', y_R', z_R')$, $O_L'(x_L', y_L', z_L')$, their radiuses are r_R' and r_L'. As GCCs parallel to detector, the GCN (guiding-cone)'s equation can be described as:

$$\begin{cases} \left(x - x_L'\right)^2 + \left(y - y_L'\right)^2 = r_L'^2 \\ 0 \le z \le z^{(R)} \end{cases} \qquad (3)$$

$$\begin{cases} \left(x - x_R'\right)^2 + \left(y - y_R'\right)^2 = r_R'^2 \\ 0 \le z \le z^{R} \end{cases} \qquad (4)$$

According to above that GDD is part of lesion, and then GPR is part of lesion cross-section.

$$\begin{cases} \left(x - x_L'\right)^2 + \left(y - y_L'\right)^2 = r_L'^2 \\ \left(x - x_R'\right)^2 + \left(y - y_R'\right)^2 = r_R'^2 \\ z_L' = \lambda \end{cases} \qquad (5)$$

Then GPR can be defined by equation (5). To acquire enough lesion tissue, we locate the puncture point at GPR's center.

The area of GPR can be described as function of *z*-coordinate; the value of GPR's area increases first and then decreases as *z* increases along positive direction. We use 'extreme method' to find the value of *z* coordinate when GPR value is at its maximum: $\frac{dS(z)}{dz} = 0$.

We can apply integral method or geometrical method to find the puncture point, but these two methods involve too many parameters so that the computation is very complicated. The approach applied in this paper is better optimized. Through studying the GPR's area, we find the relationship between GPR's area and GCC's center distance. The GPR's area becomes larger as the GCC's center distance decreases. We describe GCC's center distance as: $d_{O_LO_R} = \sqrt{(x_L' - x_R')^2 + (y_L' - y_R')^2}$, then acquiring minimum GCC's center distance using $\frac{d(d_{O_LO_R})}{d\lambda} = 0$. Then z coordinates of maximum GPR can be worked out:

$$\lambda = \frac{-b[d_2(d_1 - d_2) + d_4(d_3 - d_4)]}{(d_1 - d_2)^2 + (d_3 - d_4)^2} \qquad (6)$$

and $z_L^{(R)} - z^{(I)}{}_L = b$, $x_L^R - x_R^R = d_1$, $x_L^I - x_R^I = d_2$, $y_L^R - y_R^R = d_3$, $y_L^I - y_R^I = d_4$. According to these equations, we can calculate the other two coordinates of the puncture point via equation (1) and equation (2) above.

III. Experiment and Analysis

A. *Materials and methods*

The key procedure of breast biopsy is to locate the puncture point. We define the deviation between *z*-coordinate of puncture point and lesion-center's *z*-coordinate as *z*-location deviation σ_z. Describing the deviation between puncture-point and lesion-center as σ, thus the relation between two deviations can be expressed as: $\sigma = \sigma_z / \cos\gamma$, γ denoting the angle between X-ray and *z*-axis. Henceforth, by evaluating the value of σ_z, we can estimate σ and the deviation between lesion-edge and puncture point.

In clinic, breast should be compressed with plastic plate during the process of breast biopsy in order to avoid breast moving. In the experiment, a breast biopsy phantom model 013 from CIRS Company which contains 13 lesions was used.

The phantom is made into plat shape to simulate compressed breast. We manually acquired location of each lesion. Eight images had been acquired from 8 different angles $(\pm 10°, \pm 15°, \pm 20°, \pm 30°)$ using a digital mammography system manufactured by Anke high-tech Co. , Ltd. The image is projected at condition of 28KV -500ms-x-ray, and the diameter of x-ray beam rotation is 650mm. So we can conclude that total x-ray dose of the experiment is far lower. Puncture points' z-coordinates were acquired through the method described in the study above, and then the computed locations of lesions are compared with observed locations. Finally, estimate σ and deviation between lesion-edge and puncture target, to evaluate the feasibility of the method.

Figure 2. Breast biopsy phantom

B. *Result of Experiment*

From the experiment results: all the z-coordinates were within the expected range, and met the requirements of breast biopsy.

The distance between center of puncture-point and edge of lesion(PDL) can be described as d_1 . There is an equation: $d_1 = r - d$, d is the distance between center of lesion and puncture-point (CLP) , r denoting radius of lesion. As there are lesions of different sizes in the phantom, this study applied this standard to define the range of deviation $\delta = d_1 / r$ $(\delta \le 1)$, in order to better evaluate the experiment result.

TABLE I. EVALUATION OF DEVIATION TABLE TYPE STYLES

angle of Experimental exposure	30°	20°	15°	10°
maximum CLP (mm)	1.419	2.236	1.397	1.754
minimum PDL (mm)	0.563	0.25	1.060	0.5
average of σ	0.718	0.598	0.755	0.65
variance of σ	0.0786	0.05	0.00959	0.0476

The table I shows that all the data acquired met the requirement expected, that is, all puncture-points were included within lesions. The minimum PDL had been acquired as lesion's radius was 2 mm. According to the experiment results, the optimum data had been acquired, when the X-ray tube angle is set at 15 degrees.

IV. ANALYSIS AND CONCLUSION

To ensure the result is accurate, the GPT should be selected within certain image region. Because this method depends on X-ray cone intersection, in order to make sure that the biopsy target point is inside the lesion, operators must make sure that the spatial SGDCs should have a common area when $z = \lambda$.

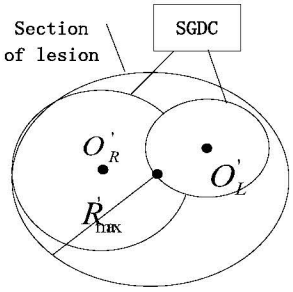

Figure 3. GCC's radius and lesion's section, the biggest circle for lesion's section, $O_R{}'$ and $O_L{}'$ for GCCs' center, $R_{\max}{}'$ for the maximumGCC's radius.

The radiuses of two GCCs are described as $r_L^{'}, r_R^{'}$. As discussed above, GCCs must be limited inside the section of lesion. The maximum radius of GCC is defined as $R_{\max}^{'}$, the maximum radius of GDC on image as $R_{\max}^{I}$, their relationship as follow:

$$\begin{cases} \dfrac{r_L^{'}}{r^{(I)}{}_L} = \dfrac{z_L^{(R)} - z^{'}}{z_L^{(R)} - z^{(I)}{}_L} \\ \dfrac{r_R^{'}}{r^{(I)}{}_R} = \dfrac{z_R^{(R)} - z^{'}}{z_R^{(R)} - z^{(I)}{}_R} \\ \dfrac{R_{\max}^{'}}{R_{\max}^{I}} = \dfrac{z_L^{(R)} - z^{'}}{z_L^{(R)} - z^{(I)}{}_L} \end{cases} \qquad (7)$$

When $z = z^{'}$, if the area of GPR is at maximum value, there is a condition $(r_L^{'} + r_R^{'} + d < R_{\max}^{'})$ that must be satisfied, d denoting the center distance between two GCCs. Because GCCs have conjoined and shared a common area, it can be inferred that: $d < r_L^{'} + r_R^{'}$. Therefore, when $z = z^{'}$, and there is intersection between GCCs, the following inequality must be satisfied: $d_{O_L O_R} = \sqrt{(x_L^{'} - x_R^{'})^2 + (y_L^{'} - y_R^{'})^2} \le \dfrac{R_{\max}^{'}}{2}$. As a result any guiding point image on the image should satisfy the relation: $d_{O_L{}' O_R{}'} \le \dfrac{R_{\max}^{I}}{2}$, and $R_{\max}^{I}$ could be derived according to the size of lesion image. If the GPTs cannot satisfy the conditions described above, then it means a GPR (common area) does not exist, so that the puncture-point could not be found.

Comparing with previous methods, the method used in this study is better optimized; no matter how small the lesion is , the puncture point calculated should be within it. Doctor could get puncture point only with two images of different projecting-angle, so it is easy to operate for this method. It could be finished within 2 minutes.

By the method, doctor should find a puncture point for the suspicious area to get enough breast tissue to judge its

condition. Even though the image area is not clear to define, we could find a appropriate puncture point to get targeted breast tissue for detection.

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