FRAMELESS STEREOTACTIC LOCALIZATION AND MULTIMODAL IMAGE REGISTRATION USING DSA/CT/MRI

BAOWEI FEI TIANGE ZHUANG
Department of Biomedical Engineering, Shanghai Jiao Tong University
Shanghai, 200030, China. Email: tgzhuang@mail.sjtu.edu.cn
JIE HU FANMIN ZHOU
Department of Neurosurgery, Shanghai Huashan Hospital
Shanghai Medical University, 200040, China

Abstract — In this paper, a novel frameless stereotactic localization method and multimodal image registration techniques for computer assisted surgery are presented. Using four external markers, the position of brain tissue can be calculated by two different DSA projection images, CT slices and MRI slices respectively. The different anatomical information (tone, soft tissue and vessel) obtained from CT, MRI and DSA can be registered together. Using DSA, the locating accuracy of phantom experiment is 0.5mm, the accuracy of skull experiment is 2.0mm. The registration accuracy of DSA/CT images of skull is 2.0-2.5mm. The volumetric representation of registered DSA and MRI images of human head shows satisfying results.

Keywords: Computer-assisted Surgery (CAS), Localization, Registration, 3D Rendering, Surgical Planning, Neurosurgery

I. INTRODUCTION

Computer assisted surgery (CAS) has made great progress in recent ten years, especially in neurosurgery[1,2]. The integration of stereotaxic method with CT scanning provided a powerful tool for neurosurgeons[3].Blood vessel is seen best on Digital Subtraction Angiography(DSA), bone is seen best on CT, while soft tissue structures are seen best on MRI. The registration of multimodal images, usually MRI and CT, can be used for surgical and radiotherapy planning[4,5] Previous work in combination of MRI and CT has made use of stereotaxic frame either screwed to skull or attached to a dental impression[6]. Frameless stereotaxic method were introduced in recent years[7]. Here, we presents a frameless stereotactic localization method and multimodal image registration technique using DSA/CT/MRI.

II. METHOD

A. The Design of Landmarks and Experiment Procedure

First, a locating plate with four legs is designed, the four tips of the legs are on the same plane and form a regular shape, the relative positions of the four tips are known. When the plate is placed on the head of the patient and the four tips contact the scalp tightly, four head marks, P_1, P_2, P_3, P_4, can be decided(see Fig.1). Second, four lead landmarks are fixed on the head marks, and two DSA images are taken with two different radiograghic views. Third, using the same landmarks, the patient is ready for CT scanning. It is important that the four landmarks are located in the same slice. Fourth, the lead landmarks are replaced by CuSO4 landmarks, the patient is ready for MR scanning, it is also important that the four landmarks are in the same slice. Using the four landmarks, the position of the target can be determined by two DSA images, CT or MRI images respectively, the registration between any two modalities can be performed.

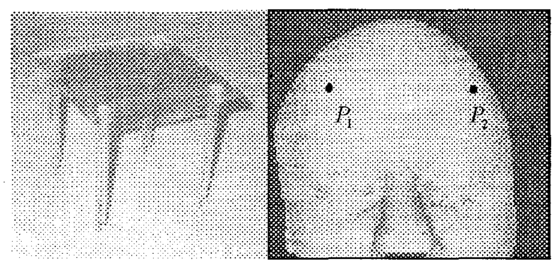

Fig.1 The locating plate with four legs and the head marks.

B. Frameless Stereotactic Localization Method

The DSA coordinate system (DCS) is defined with the origin located at the X-ray source A_{DSA}. $\{X_{DSA} Z_{DSA}\}$ is parallel to the detector plane. Y_{DSA} axes is perpendicular to the detector plane and intersect it at A'_{DSA}. The distance between A'_{DSA} and A_{DSA} is D ($D = A_{DSA}A'_{DSA}$). P_1, P_2, P_3, P_4 are four different points on the same plane. The distances between any two points are known: $l_{1-2}, l_{1-3}, l_{1-4}, l_{2-3}, l_{2-4}, l_{3-4}$ (See Fig. 2).

$\{x_i, y_i, z_i\}$ is the coordinates of P_i (i=1,2,3,4) in DCS. $\{x'_i, D, z'_i\}$ is the coordinates of the projection point, P'_i, of P_i in DCS. The following equations can be obtained:

$$x'_i = x_i \cdot D / y_i \qquad (i=1,2,3,4)$$

$z_i' = z_i \cdot D / y_i$ (i=1,2,3,4)

$l_{i-j}^{\;2} = (x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2$

($i \neq j$, i, j = 1, 2, 3, 4)

The coordinates of projection point P_i' (x_i', D, z_i') and the distance $l_{i-j} (i \neq j)$ are known. There are thirteen unknown parameters: $\{x_i, y_i, z_i\}$ (i=1 ~ 4) and D, while the equations are fourteen, the results can be obtained [8,9].

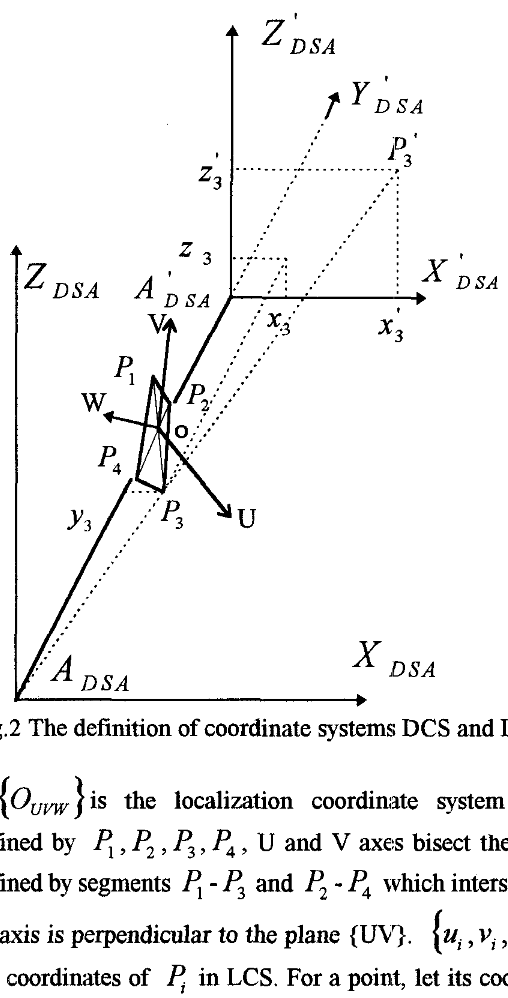

Fig.2 The definition of coordinate systems DCS and LCS

$\{O_{UVW}\}$ is the localization coordinate system (LCS) defined by P_1, P_2, P_3, P_4, U and V axes bisect the angles defined by segments P_1-P_3 and P_2-P_4 which intersect at O, W axis is perpendicular to the plane {UV}. $\{u_i, v_i, w_i\}$ is the coordinates of P_i in LCS. For a point, let its coordinate in DCS be $\{x_{DSA}, y_{DSA}, z_{DSA}\}$, and its coordinates in LCS be $\{u, v, w\}$. The coordinates transformation of the point from DCS to LCS can be expressed as:

$$[x_{DSA} \;\; y_{DSA} \;\; z_{DSA} \;\; 1] = [u \;\; v \;\; w \;\; 1] \bullet M_{DSA}^{LOC} \quad (1)$$

$$[u \;\; v \;\; w \;\; 1] = [x_{DSA} \;\; y_{DSA} \;\; z_{DSA} \;\; 1] \bullet M_{LOC}^{DSA} \quad (2)$$

M_{DSA}^{LOC} and M_{LOC}^{DSA} can be obtained by the coordinates of P_1, P_2, P_3, P_4 in DCS and LCS.

T is the target whose position in LCS is unknown. Assuming, a projection a is performed. The source is A. The projection point of the target T is T_a' in the detector plane a. Using (2), the coordinates of A and T_a' in LCS can be calculated and the equation of AT_a' can be obtained. The same is for a second projection b in a different view angle. The equation of BT_b' in LCS can be obtained. T is the intersection of line AT_a' and line BT_b' in LCS. Therefore, on the basis of two different projection images, the coordinates of any point in LCS can be obtained.

The CT coordinate system (CCS) and the MRI coordinate system (MCS) are defined with their origins located at the top-left of the first CT/MRI slice. Let $\{x_{CT}, y_{CT}, z_{CT}\}$, $\{x_{MRI}, y_{MRI}, z_{MRI}\}$ be the coordinates of the target T in CCS and MCS respectively, $\{u, v, w\}$ be the coordinate of T in LCS. The coordinate transformation between CCS/MCS and LCS can be expressed as :

$$[x_{CT} \;\; y_{CT} \;\; z_{CT} \;\; 1] = [u \;\; v \;\; w \;\; 1] \bullet M_{CT}^{LOC} \quad (3)$$

$$[u \;\; v \;\; w \;\; 1] = [x_{CT} \;\; y_{CT} \;\; z_{CT} \;\; 1] \bullet M_{LOC}^{CT} \quad (4)$$

$$[x_{MRI} \;\; y_{MRI} \;\; z_{MRI} \;\; 1] = [u \;\; v \;\; w \;\; 1] \bullet M_{MRI}^{LOC} \quad (5)$$

$$[u \;\; v \;\; w \;\; 1] = [x_{MRI} \;\; y_{MRI} \;\; z_{MRI} \;\; 1] \bullet M_{LOC}^{MRI} \quad (6)$$

C. Registration of DSA/CT/MRI

Five steps are followed when a point is to be transferred from CT/MRI slices to DSA images:

(i) The position of the point in CCS or MCS is determined.
(ii) The coordinate of the point in LCS is calculated.
(iii) The coordinate of the point in DCS is calculated.
(iv) Projecting algorithm is performed to obtain the coordinates of the projection point in DCS.
(v) The position of the point in DSA image is calculated.

When a target is transferred from DCS to CT/MRI slice, (I) two DSA images of different radiographic views are used to calculate the position of the target in LCS; (II) the position of the target in CT/MRI slices is calculated. It is relatively simple to transfer coordinate between CT and MRI images.

The coordinate transformation between any two systems of DCS, CCS and MCS can be expressed as:

$$M_{CT}^{DSA} = M_{LOC}^{DSA} \bullet M_{CT}^{LOC}, \quad M_{DSA}^{CT} = M_{LOC}^{CT} \bullet M_{DSA}^{LOC}$$

$$M_{MRI}^{DSA} = M_{LOC}^{DSA} \bullet M_{MRI}^{LOC}, \quad M_{DSA}^{MRI} = M_{LOC}^{MRI} \bullet M_{DSA}^{LOC}$$

$$M_{MRI}^{CT} = M_{LOC}^{CT} \bullet M_{MRI}^{LOC}, \quad M_{CT}^{MRI} = M_{LOC}^{MRI} \bullet M_{CT}^{LOC}$$

III. EXPERIMENT AND RESULTS

The GE Advantx DX DSA System, SHIMADZU SCT-5000T and GE MR LORIZON LX 1.5T are used for DSA, CT and MRI data acquisition respectively.

A. Localization experiments Based on DSA

(1) Phantom experiment. Ten lead balls , P_1 - P_9 and T, with radius 0.5mm, are placed on a plexiglass plate. P_1, P_2, P_3, P_4 constitute a square whose side is 50.8mm. The center of the square is T. The focal spot of DSA is selected as 0.15mm. The results show that the localization accuracy is 0.5mm.

(2) Skull Experiment. Four lead balls which are 1.0mm in radius are fixed on the skull as the landmarks, P_1, P_2, P_3, P_4. At the same time, six testing balls, P_5 - P_{10}, are fixed on the skull. The focal spot of DSA is selected as 0.3mm. The results show that the localization accuracy is 2.0mm.

B. Registration and Visualization of Skull Using DSA/CT

In this experiment, two lead wires which simulate vessels are fixed in the skull. Several lead balls are linked by the lead wires. After the landmarks are well placed, the skull is undertaken CT scanning and DSA projecting. The parameters of CT scanning are : 120kV, 160mA, 2.0sec, 320mAs, S/2mm, X=0, Y=0, M=1.00, TM=1.00, A=214mm, Level =350, Width =1500. The registered DSA/CT images gives satisfying results, the registration error is 2.0-2.5mm.

C. Registration and Visualization of Head Using DSA/MRI

The patient is a 69 years old woman. There is a large tumor on the left side, and the vessels are very near to the tumor. A point which might be a vessel is not very clear in MRI images, it can be transferred to DSA images on which vessel can be clearly displayed. If the point is really a vessel, it can be highlighted in MRI images. The tumor in MRI slices were segmented and colored in a different color.

IV. DISCUSSION

One key issue is the locating accuracy and the registration error. There are several aspects that affect the accuracy. The first is the size of the focus spot of DSA equipment. The focus spot we used is 0.15mm and 0.3mm. The second is the size of landmarks. The radius of the lead ball is 0.5mm, the radius of the CuSO4 landmarks is 1.0mm. The third is the slice thick of CT and MRI which are 2.0mm and 3.8mm respectively.

V. CONCLUSION

We have presented a novel frameless stereotactic localization method and multimodal image registration techniques for computer assisted surgery. Using four external markers, the position of brain tissue can be calculated by two different DSA projection images, CT slices and MRI slices respectively. The different anatomical information (tone, soft tissue and vessel) obtained from CT, MRI and DSA can be registered together. Using DSA, the locating accuracy of phantom experiment is 0.5mm, the accuracy of skull experiment is 2.0mm. The registration accuracy of DSA/CT images of skull is 2.0-2.5mm. The volumetric representation of registered DSA/MRI images of human head shows satisfying result.

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