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Automatic Head CT Images Prescriptions and Reformations

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Abstract

In this paper, we developed an automatic method to implement a new head CT clinical protocol that currently manually performed by neuroradiologists. The proposed method is composed of three steps. At first, automatically detect the mid-sagittal plane in three-dimensional head images. The algorithm computed similarity measures between the two sides of the head. We defined the mid-sagittal plane as exhibiting maximum symmetry with respect to the image volume. The choice of the initial plane is crucial to success of the algorithm. Therefore, we estimated the initial mid-sagittal plane as the plane passing through the principal axes of the head. Secondly, automatically extract hard palate on the reformatted mid-sagittal plane and angle 12 degrees from hard palate. Finally, according to the clinical protocol, reformatted axial slices and maxillofacial coronal image that perpendicular to the hard palate were generated. Results were evaluated by visual inspection by neuroradiologist and were judged to be consistently correct.

1. Introduction

CT (Computer Tomography) head scans have been traditionally prescribed parallel to the orbito-meatal line (OML), defined as passing through the lateral canthus and middle of the external ear canal. However, using this external reference line for CT prescriptions has several major drawbacks [1]. So a new clinical head CT protocol is developed to improve CT precision and approximate the Talairach reference standard using the hard palate as a landmark [1]. Fig.1 illustrates the new protocol in which axial scan pitch is angled 12^o (dotted lines) from a line passing through the hard palate (solid line).

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In order to implement this new head CT protocol, technologists take steps as follows [2]. A proper head coordinate system centered in the head is defined (Fig.2).

Step 1. Roll & yaw correction： Manually identify two similar contralateral points on source axial images, e.g. round window niche basal turn of cochlea. Then generate mid-sagittal plane bisecting contralateral points (Fig.1).

Step 2. Pitch correction: Manually identify plane of hard palate on the mid-sagittal slice. Then angle +12^o (clockwise) from a line passing through the hard palate (HP).

Step 3. Reformat the axial scan prescription with the HP+12^o (Fig.1 dotted lines), and coronal planes perpendicular to HP (Fig.1 dashed lines).

From above, manual operations of the protocol are so tedious and time consuming. So we are motivated to find an automated method of performing the protocol. The key points and difficulties of the performance are automatic identification mid-sagittal plane and hard palate.

In this paper, we present an automated method for the protocol. In section 2, we describe the approach of automatic detection mid-sagittal plane. In section 3, we present the method for identifying hard palate. In section 4, we apply the method to CT images and show the results. Conclusion is given in section 5.

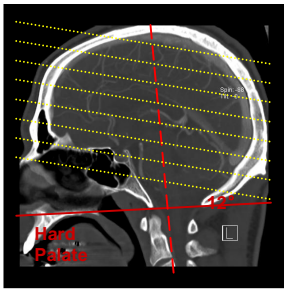


Fig.1 Mid-sagittal CT plane illustrating the axial scan prescription (yellow dotted lines) and line passing through the hard palate (red solid line)

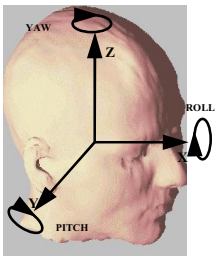


Fig.2 Head coordinate system. Positive X, Y and Z point to the anterior, right and superior directions respectively. The plane Y=0 is defined mid-sagittal plane. Original axial image is perpendicular to Z axis. (Head image comes from www.mathworks.com)

2. Mid-sagittal plane detection

Mid-sagittal plane refers to a proper plane to split the head into two roughly identical parts from left to right. The basic idea to detect mid-sagittal plane is using anatomical symmetric information. But because of the tilt of head position during scanning process, the homologous anatomical structures in both hemispheres are not displayed in the same axial slice of the three-dimensional images. This makes detection mid-sagittal plane is a challenge problem in medical image processing area. Several papers have previously considered this problem. There are mainly two classes of methods aimed at finding the mid-sagittal plane. One is finding the plane best matching the cerebral interhemispheric fissure [3, 4]. The other is finding the plane maximizing a symmetry criterion [5, 6, 7, 8]. But the intrinsic curvature of the fissure and normal and abnormal asymmetries modifying the underlying symmetry of the brain limit the accuracy and robustness of these methods.

In this section, we present a new approach to automatically compute the mid-sagittal plane in 3D volumetric images. This method composed of two steps. At first, estimate the initial mid-sagittal plane. Then define a criterion to measure symmetry and search the plane to maximize this criterion.

2.1. Extract the principal axes of head

In order to increase the accuracy and robustness of our algorithm, we use the plane passing through the principal axes of the head as the initial mid-sagittal plane.

Extraction approach for principal axes is as follows:

(1) Extract the skull. The skull is obtained by finding the largest region after applying region growing algorithm on all pixels with bony density [9] slice by slice. Then we can determine a binary volume $F(x, y, z)$ to represent the shape of the head.

(2) Compute the centroid and principal axes following [10]. The principal axes are the eigenvector of the inertia matrix:

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

where

$$I_{xx} = \sum_i \left[(y_i - y_c)^2 + (z_i - z_c)^2 \right]$$

$$I_{zz} = \sum_i \left[(x_i - x_c)^2 + (y_i - y_c)^2 \right]$$

$$I_{xy} = \sum_i (x_i - x_c)(y_i - y_c)$$

$$I_{yz} = \sum_i (y_i - y_c)(z_i - z_c)$$

$$I_{zx} = \sum_i (z_i - z_c)(x_i - x_c)$$

$$x_c = \frac{\sum_i x_i}{N}, \; y_c = \frac{\sum_i y_i}{N}, \; z_c = \frac{\sum_i z_i}{N}$$

and (x_c, y_c, z_c) is the centroid of the skull. The normalized eigenvector matrix of I is given by

$$E = \begin{bmatrix} e_{11} & e_{12} & e_{13} \\ e_{21} & e_{22} & e_{23} \\ e_{31} & e_{32} & e_{33} \end{bmatrix} \text{ and satisfy } E = R$$

Where R is the rotation matrix. Let α, β and γ are the rotation angles with respect to x, y and z axes respectively, they are calculated as:

$$\beta = \arcsin(e_{31})$$

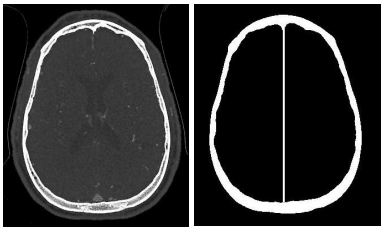
$$\gamma = \arcsin(-e_{21} / \cos\beta)$$

$$\alpha = \arcsin(-e_{32} / \cos\beta)$$

The axial images are centered to the centroid and rotated to turn the center axis vertical. The principal axes are determined as midlines on each slice. Fig.3 shows the extracted skull and midline on a slice.

(a) (b)

Fig.3 (a) Orignal CT image (b) Skull extraction and estimated midline



2.2 Compute the mid-sagittal plane

In this section, in order to detect the mid-sagittal plane, we define a criterion to measure symmetry and find the plane that maximizes this criterion. The criterion is the cross correlation between the original image F and its reflect(flipped) image G [6]

$$CC(F,G)=\frac{\sum_{i=1}^{N}(f_i-\bar{f})(g_i-\bar{g})}{\sqrt{\sum_{i=1}^{N}(f_i-\bar{f})^2\sum_{i=1}^{N}(g_i-\bar{g})^2}}$$

where, f_i, g_i are the intensities of voxels $F(x_i,y_i,z_i)$ and $G(x_i,y_i,z_i)$, $\bar{f}$ and $\bar{g}$ are the mean intensity of F and G, N is the number of voxels in the search region.

According to the coordinate system (Fig.1), the mid-sagittal plane can be presented as

$$P(x,y,z)=ax+by+cz-1=0$$

We use an exhaustive search of the parameter space for the optimal mid-sagittal plane. Because the selection of the initial plane for optimization is crucial to the success of the search, we choose the initial plane is passing through the centroid and principal axes of the head. Our search procedure is to rotate the initial plane by discrete angle in the 3-D and compute $CC(F,G)$ for all the corresponding planes. The mid-sagittal plane is found when maximum of $CC(F,G)$ is obtained.

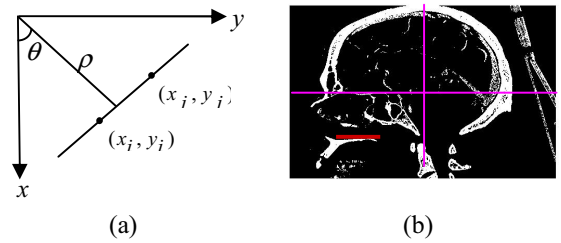
3. Identify hard palate on the mid-sagittal

After detection of the mid-sagittal, we reformat the mid-sagittal from the original axial images. To perform new head CT protocol, hard palate is identified on the mid-sagittal plane for pitch correction of CT image.

Hough transform is used to find the hard palate line. First, a binary image is obtained by a bony intensity threshold. Then we constrain the detection region to the bottom-left of the image and detect the line approaches horizontal direction (Fig.4(b)). The straight lines in the image can be parameterized in the form

$$\rho=x\cos\theta+y\sin\theta$$

Where ρ is the perpendicular distance from the origin and θ is the angle of distance vector measured anticlockwise from x-axis (Fig.4(a)). The detection of lines becomes the localization for peaks in the parameter space. The algorithm is described by the following steps [11]: (1) Compute Hough transform on the binary mid-sagittal image; (2) Find Hough transform peaks that are likely to be significant; (3) Find and link line segments. Fig.4(b) shows the resulting image with the detected hard palate line superimposed as red line.



(a) (b)

Fig.4. (a) Parameterization of line in the xy-plane (b) Binary image and extracted line of hard palate

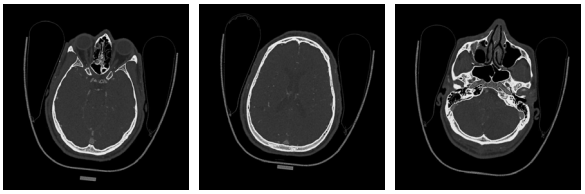
4. Experimental results

In this section, the proposed method to automatically implement the new head CT protocol was investigated using 600 brain CT images. All the images were provided by University of Cincinnati Medical Center. The results from all 600 images were inspected by expert neuroradiologist and were judged to be highly accurate. The experiment consists of three parts:

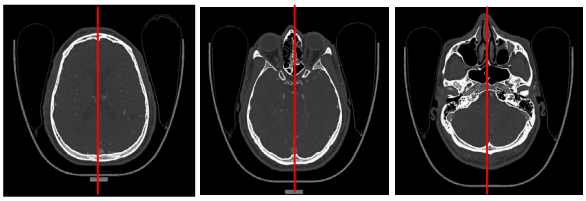
(1) Automatic detection of the mid-sagittal plane using axial slices. Fig.5(a) shows original tilted CT axial slices, Fig. 5(b) shows the correction of the image and detected midline on the axial slice. Then we generate the mid-sagittal plane according to the midline of the axial slices. The reformated mid-sagittal plane is displayed in Fig.6(a).

(2) Automatic identification hard palate and correction mid-sagittal plane by angling 12 degrees from hard palate. Hard palate is a relatively planar midline structure fixed to the skull and projects as a line on the sagittal slice. Fig.6(b) is the corrected sagittal image.

(3) Reformat axial slices as the direction of dash line and maxillofacial coronal slice that perpendicular to the hard palate as dash-dot line showing in Fig. 6(b). One of reformatted axial slices and maxillofacial coronal slice are displayed in Fig. 7.

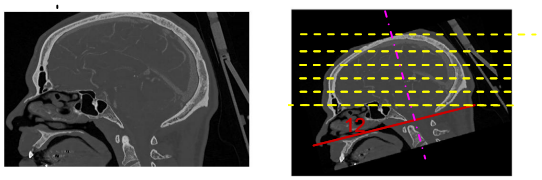


(a)



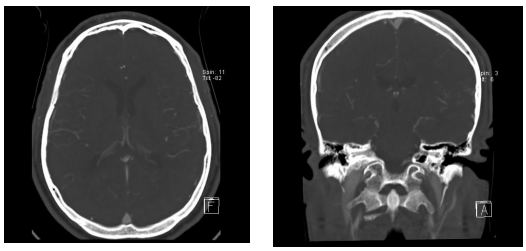
(b)

Fig.5 (a) Original tilted axial images. (b) Position correction and the detected midline on the axial image



(a) (b)

Fig.6 (a) Reformatted mid-sagittal image (b) Corrected mid-sagittal image and direction of hard palate (red solid line), reformatted axial slices (yellow dash lines) and coronal slice (pink dash-dot line)



(a) (b)

Fig.7 (a) Reformatted axial slice (b) Reformatted coronal image

5. Conclusion

In this paper, we developed an automatic method to implement a new head CT clinical protocol that currently manually performed by neuroradiologists. The key points and difficulties in the implementation are automatic identification mid-sagittal plane and hard palate. The proposed method consists of three steps: (1) Automatic detection of the mid-sagittal plane in three-dimensional head images. The mid-sagittal plane exhibits maximum symmetry between the two sides of the head. We defined a criterion to measure symmetry and find the plane that maximizes this criterion. Selecting an appropriate initial plane for searching is crucial to success of the algorithm. Therefore, we estimated the initial mid-sagittal plane as the plane passing through the principal axes of the head. (2) Automatic identification hard palate on the reformatted mid-sagittal plane and 12 degrees was angled relative to hard palate. (3) According to the clinical protocol, reformatted axial slices and maxillofacial coronal image that perpendicular to the hard palate were generated. Experimental results were investigated by visual inspection by neuroradiologist and were judged to be consistently satisfied.

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