Extended Talairach Landmarks on Neuroimages for Atlas Registration

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Abstract—The accuracy of scan-to-atlas registration highly depends on the number of landmarks and the precision of landmark identification. An extended landmark, cerebellum inferior (CBI), is introduced in this paper. The extracted brain and midsagittal plane are applied to identify the modified Talairach landmarks and the new introduced landmark CBI. The AC-PC plane is firstly determined and then anatomical information is applied to estimate the other landmarks. The proposed method is fully automatic and has been validated on 49 FDG-PET normal and pathological scans qualitatively, and 15 cases quantitatively. The average processing time is about 3 seconds on a standard personal computer.

Keywords-Talairach; landmarks; atlas; transformation

I. INTRODUCTION

Atlas-assisted operations on medical images of human brain are widely applied to image segmentation [1, 2], data normalization [3], and localization analysis [4-6], especially for the positron emission tomography (PET) images with a poorer spatial resolution and lower signal-noise ratio than other modalities like magnetic resonance imaging or computed tomography. PET is a nuclear medicine imaging technique to produce a three dimension (3D) image of functional processes in the body, by a tracer injected into a patient. Fluoro-deoxy-glucose (FDG) is a commonly used tracer to distinguish the high-glucose-consuming cells, e.g. the cerebrum and cerebellum, from the other parts of the body [7]. This imaging technique is increasingly used for detection and diagnosis of tumor and neurological diseases, e.g. Alzheimer’s disease.

There are numerous printed and electronic brain atlases have been developed [8, 9]. Talairach and Tournoux introduced a brain atlas [10], which is commonly used as a reference brain and a gold standard in human brain mapping. The original Talairach landmarks contain two subcortical landmarks, anterior commissure (AC) and posterior commissure (PC), and six cortical landmarks. However, the original Talairach landmarks have several limitations and problems, e.g. not all of the landmarks are available on the Talairach atlas. A set of modified Talairach landmarks, conceptually equivalent to the original Talairach landmarks, was introduced [8] to overcome the problems and become more constructive and easier to be identified by computer program. The modified Talairach landmarks are automatically identified on magnetic resonance neuroimages [11, 12], and applied to the Talairach transformation [4] and other atlas-assisted automatic interpretations and applications [5, 6].

In this paper, a new landmark is introduced for the cerebellum inferior (CBI), which is at the most inferior point of the cerebellum, to enclose the cerebellum into the Talairach space for rapid Talairach transformation. After adding the new landmark, the whole brain will be subdivided into 18 cuboidal regions including both cerebrum and cerebellum (as opposed to the original 12 cuboids) by 9 landmarks – CBI plus 8 modified Talairach landmarks.

II. BACKGROUND

A. Original and Modified Talairach Landmarks

Figure 1. Modified Talairach landmarks on a) axial; b) coronal; and c) sagittal orientations.

1) Original Talairach Landmarks

The original Talairach landmarks define two internal landmarks AC and PC, and six external landmarks L, R, A, P, S, and I [10]. AC is the point of intersection of the lines passing through the superior edge of the anterior commissure and the posterior edge of the anterior commissure. PC is the point of intersection of the lines passing through the inferior edge of the posterior commissure and the anterior edge of the posterior commissure. The external landmarks are the points on the cortex. They are: the most superior point of the parietal cortex (S) and the most inferior point of the temporal cortex (I); the most anterior point of the frontal cortex (A) and the most posterior point the occipital cortex (P); the most lateral points (left and right) of the parietotemporal cortex (L and R). The original Talairach landmarks have some limitations and several problems such as, not all of the landmarks are available in the original brain atlas; the cortical landmarks are not defined in a constructive way; the intercommissural landmarks are located beyond their own structures; etc.

2) Modified Talairach Landmarks

The modified Talairach landmarks [8] define AC and PC within the midsagittal plane (MSP), and are the central points...
The automatic approach of landmark placement is based on our previous work on brain extraction and midsagittal lines detection from FDG-PET images [14] shown in Fig. 4. The proposed method comprises two parts: 1) the modified Talairach landmarks identification; and 2) the extended landmark CBI placement on FDG-PET images.

### Detection of the modified Talairach landmarks

The modified Talairach landmarks are detected by the following steps: a) detect AC-PC line (APL) on MSP; b) determine L, R, A, P landmarks on AP plane; c) determine I on VAC plane, and decide AC position; and d) determine S on VPC plane, and decide PC position.

#### a) Detect AC-PC line (APL) on MSP

APL is an intersection line of MSP and AC-PC plane, which is a perpendicular plane to MSP and passes through both the AC and PC. The detection of APL is the first and important step to extract the AC-PC plane and affect the results of the subsequent steps to detect the other landmarks. Since FDG-PET images lack structural information, it is difficult to detect the anterior commissure and posterior commissure structure on PET images. An alternative way to estimate the APL from MSP is to detect the longest line from anterior to posterior (Fig. 5) on the MSP image with skull removed. Even though the exact positions of AC and PC are still unsure, they will be determined later by the inferior and superior landmarks according to the modified Talairach space.

The algorithm to detect the longest line from MSP is by searching the projections from both anterior and posterior directions. On a 2D image of MSP (Fig. 5), the searching is from both the left and the right of the image. Since APL has its anatomical position within human brain, the proportional scaling in the Talairach space (e.g. the distance between A and P is 174mm, the distance between S and APL is 74mm, and the distance between I and APL is 43mm) is applied to the search algorithm. After the detection of the longest horizontal line, the MSP image needs to be rotated through a degree of $\lambda$ (e.g. 10°) to find out the longest line from non-horizontal direction. It can be done by a loop of rotation from $-\lambda$ to $+\lambda$ with step 1°.

### B. Materials

The proposed approach of automatic landmark placement was evaluated with the FDG-PET images from the Alzheimer’s Disease Neuroimaging Initiative (ADNI) database. Each case has 6 dynamic frames with scanning every 5 minutes from 30 to 60 minutes after FDG injection. Those scans were preprocessed by the following steps: 1) registered to the first frame, 2) averaged, 3) reoriented into a grid of 160×160×96 voxels with voxel size 1.5×1.5×1.5mm [13]. The preprocessed images have their horizontal axis paralleled with the anterior commissure and posterior commissure.
b) **Determine L, R, A, P on AC-PC plane**

AC-PC plane (Fig. 6) is extracted from the volumetric data based on APL and the skull-stripped brain [14]. The algorithm to determine the L and R landmarks is to select the extreme left point and extreme right point as L and R landmarks by searching the lines parallel to MSP. Similarly, to determine the A and P landmarks, the extreme anterior point and extreme posterior point are selected by searching the lines perpendicular to MSP [14]. Fig. 6 shows the AC-PC plane with L, R, A, P landmarks identified.

![Figure 6. AC-PC plane with L, R, A, P landmarks.](image)

**Figure 6.** AC-PC plane with L, R, A, P landmarks.

c) **Determine I and AC**

In the Talairach space, the length from anterior to posterior is 174mm. The distances from anterior to AC and PC are 70mm and 94mm, respectively. They are about 40% and 54% of the whole line. According to the definition of the Talairach space and the positions of A and P, the AC and PC positions are estimated by proportional scaling. They are marked as estimated-AC (eAC) and estimated-PC (ePC). The coronal slices near eAC (e.g. ±5mm) are selected as the candidates of VAC. By calculating the most inferior point on all VAC candidates, the VAC is identified and the AC is also determined at the same time. Fig. 7a shows an example of I on VAC.

![Figure 7. I, S, AC and PC landmarks. (a) I landmark on VAC; (b) S landmark on VPC; (c) A, C and PC on MSP.](image)

**Figure 7.** I, S, AC and PC landmarks. (a) I landmark on VAC; (b) S landmark on VPC; (c) A, C and PC on MSP.

d) **Determine S and PC**

Similarly, the coronal slices near ePC (e.g. ±5mm) are selected as the candidates of VPC. By calculating the most superior point on all VPC candidates, the VPC is identified and the PC is also determined at the same time. Fig. 7b shows an example of S on VPC, and Fig. 7c shows AC and PC on MSP.

determine the extended landmark CBI on FDG-PET images

A coronal slice passing through the most superior point of cerebellum is called VCB. The extended landmark CBI will be located by the following steps: a) estimate the position of VCB (eVCB) and select the candidates of VCB; and b) Locate CBI from the candidates of VCB.

a) **Estimate the position of VCB (eVCB) and select the candidates of VCB**

In order to estimate the position of VCB, a transverse fissure cerebellar tentorium, is detected first. It is located between cerebrum and cerebellum [15]. According to the FDG-PET image property of that the cerebrum and cerebellum have much greater glucose uptake values than the other fissures [16, 17], the fissure between cerebrum and cerebellum is detected by the following steps:

Define a region-of-interest (ROI) for faster detection of cerebellar tentorium. The ROI of X-axis starts from PC and ends at P. The ROI of Y-axis starts from APL and ends at the bottom of MSP image. All the processing and calculation below are restricted within this ROI (Fig. 8a).

![Figure 8. Estimated VCB plane. (a) ROI definition; (b) GCL calculation](image)

**Figure 8.** Estimated VCB plane. (a) ROI definition; (b) GCL calculation

b) **Locate CBI from the candidates of VCB**

The cerebellum has two hemispheres connected by the vermis. There are two conditions need to be considered while calculating the lowest part on coronal images. The most inferior bottom points of cerebellum are lower than the vermis and higher than the brainstem. As the size of the brainstem is wider than that of the vermis, the width about 7mm is excluded from both hemisphere sides for calculation of cerebellum bottom. The CBI is located by the following steps:

- Exclude the areas which may contain the brainstem and vermis from the coronal images.
- Detect the lowest part on both hemispheres and calculate the average.
- Find out a slice with lowest average value of the cerebellar hemispheres. The slice is VCB, and the most inferior point on VCB is the landmark CBI.

IV. RESULTS

The proposed approach of automatic landmark placement on FDG-PET images was implemented in C++ running on a standard personal computer with 2.4GHz CPU. The average processing time was 2.78 seconds per case. A total of 49 cases
with a resolution of 160×160×96 voxels of size 1.5 mm³ were tested. Fifteen of them have the landmarks manually placed by a neuroanatomy expert for comparison with the results of the automatic method. Fig. 9 gives an example of grid by detected landmarks on three orientations of FDG-PET images. The other cases were visually checked with satisfactory results.

Table 1 lists the differences of 15 cases, and their minimum and maximum values, mean and the standard deviations (SD) of the displacements of comparing the automated landmark identification and the manual method for the modified Talairach landmarks AC, PC, L, R, A, P, S, I, and CBI. The differences of other landmarks are the simple absolute difference value of ground truth and automatic approach. From the result table, there is no significant statistical difference was observed.

### V. CONCLUSION

In conclusion, a new landmark is introduced to extend the modified Talairach landmarks in order to include cerebellum into the Talairach space and grid system. A fast and fully automatic approach to identify those landmarks from FDG-PET images is presented. It has been applied to 49 cases and shown promising results. Although the proposed approach has several limitations, we believe that our method is useful by providing an automatic Talairach transformation for FDG-PET images.

### VI. ACKNOWLEDGMENT

The data for this study have been obtained from the Alzheimer’s Disease Neuroimaging Initiative (ADNI) database (www.loni.ucla.edu/ADNI).

### REFERENCES