

MEDICAL IMAGE PROCESSING

Field of the invention

The present invention relates to medical image processing, and relates more particularly to imaging techniques that can be used for identifying and segmenting the central sulcus and Sylvian Fissure in cranial images.

Background

Various authors have contributed to medical knowledge concerning automatic segmentation of sulci, but little literature exists concerning segmentation of the central sulcus (CS) and the Sylvian Fissure (SF).

The central sulcus (CS) separates the parietal from frontal lobes. The CS starts in or near the superomedial border, slightly behind the midpoint between the frontal and occipital poles. The CS runs sinuously downwards and forwards for about 8 to 10 cm to end slightly above the posterior ramus of the lateral sulcus, from which it is always separated by an arched gyrus.

The Sylvian Fissure (SF) is a cleft rising at a sharp angle, seen in both hemispheres of the brain, but more pronounced in the left. The cleft runs between Broca's area and Wernicke's area, both parts of the left hemisphere known to be implicated in language function. The SF plays very important role in parcellation, or division, of the cortical surface.

Both the CS and the SF are cerebrospinal fluid (CSF), though there are other CSFs as well. A selective survey of some of these techniques for segmentation of sulci is described.

Lohmann et al [Lohmann G., Cramon, D.Y.V., "Automatic labeling of the human cortical surface using sulcal basins", *Medical Image Analysis*, 2000; 4: 179–88] propose segmenting the sulcal basins, as the union of the sulci and gray matter. *Rettmann et al*

[Rettmann, M., Han X., Xu C., Prince J.L., “Automated sulcal segmentation using watersheds on the cortical surface”, *NeuroImage*, 2002; 15: 329–44] use watersheds to segment the sulcal regions, which are also taken to be the union of sulci and gray matter.

Mangin et al [Mangin, J.F., Frouin, V., Bloch, I., Regis, J., Lopez-Krahe, J. “From 3D magnetic resonance images to structural representations of the cortex topography using topology preserving deformations”, *Journal of Mathematical Imaging and Vision*, 1995; 5(4): 297–318] used *k*-means to find the union of sulci and gray matter. *Renault et al* [Renault, C, Desvignes, M., Revenu, M., “3D curves tracking and its application to cortical sulci detection”, *Proceedings of the 2000 IEEE International Conference on Image Processing*, vol. 2: 491–4] propose a curve tracking technique for sulci detection.

The above authors are unable to report identifying any specific sulcus, due to the partial volume effect of the magnetic resonance images (MRIs).

Manceaux-Demiau et al [Manceaux-Demiau A, Bryan RN, Davatzikos C. A probabilistic ribbon model for shape analysis of the cerebral sulci: applications to the central sulcus. *Journal of Computer Assisted Tomography* 1998; 22(6): 962–71] proposed to quantify the central sulcus through probabilistic geometric features like curvature through training provided that the segmentation is available. *Tao et al* [Tao, X., Han, X., Rettmann, M., Prince J., Davatzikos, C., “Statistical study on cortical sulci of human brains”, *Proceedings of Information Processing in Medical Imaging*, 2001; 475–87] also used statistical features to quantify sulci.

There is no available method identifying and localizing the central sulcus from magnetic resonance images. The above-mentioned techniques are unsuitable for segmenting the Sylvian Fissure due to its complex anatomy. A need clearly exists for an improved technique of identifying the Sylvian Fissure.

Summary

Currently there are no automated techniques for identifying and localizing the central sulcus (CS) and the Sylvian Fissure (SF). One possible technique is to identify and

localize the CS and SF through manual editing of the segmented sulcal basins (a union of the cerebrospinal fluid and the gray matter), though this procedure is tedious and prone to error.

The central sulcus (CS) and Sylvian Fissure (SF) are both cerebrospinal fluid (CSF) as noted above. Both the SF and the CS are important in quantifying the cortical surface. These regions share similar spatial features. Both display folds having a long and narrow structure, and are consequently affected by the partial volume effect. In acquired MRI images, the SF and the CS are represented as close in intensity, and both are classified as CSF. These similarities mean that the approach to segmentation of both the SF and the CS shares some common characteristics.

Both the CS and the SF suffer problems relating to the partial volume effect and noise when segmentation is attempted. Existing techniques are thought to fail when applied to segmentation of the CS and SF, as existing techniques consider CSF as a whole, and are unable to identify the CS and SF, let alone separately segment each component. Further, the segmentation of CSF may not be complete due to the partial volume effect, and the lack of any anatomical guidance, namely anatomical knowledge that can be used as a reference to guide the approach to segmentation.

The technique described herein, by contrast, use features (both anatomical and gray-level) to identify the CS and SF, and accurate segmentation is able to be subsequently performed. That is, accurate segmentation is performed only when one is sure that the CSF relates either to the CS or the SF. As well as segmentation, the MSP and the landmarks such as the anterior commissure (AC) and the posterior commissure (PC) are used to automatically identify the position of the SF or the CS in MR images.

Segmentation methods for the CS and SF both involve the identification of the ROI relative to the MSP and the landmarks. Also, both procedures segment the sulcal basins for further refinement. Both methods derive the skeleton of the sulcal basin previously obtained and determine those voxels that can be classified as CSF, and which represent tissue connected to the skeleton.

The techniques described herein can automatically identify and localize the CS and the SF (the cerebrospinal fluid) for cranial magnetic resonance imaging (MRI) applications. The volumetric data is reformatted with respect to the midsagittal plane and the AC and PC. The central sulcal basin is the sulcal basin with the maximum volume. The Sylvian sulcal basin is identified from the Y-shaped sulcal basin in the coronal slice, or coronal section, passing through the AC. The sulcus/fissure is the union of the skeleton of the corresponding basin and sulcus/fissure connected to the skeleton.

According to an aspect of the invention, there is provided an automated method of segmenting the central sulcus and Sylvian Fissure regions in magnetic resonance image (MRI) image data representing brain tissue, comprising: reformatting said MRI image data representing brain tissue to a predetermined spatial orientation dependent upon the midsagittal plane, the anterior commissure and the posterior commissure; determining spatial statistics relating to spatial features of the represented brain tissue; classifying the represented brain tissue within categories of white matter, gray matter and cerebrospinal fluid; identifying a region of interest in the represented brain tissue classified as cerebrospinal fluid based on anatomical knowledge of the Sylvian Fissure and the Central Sulcus; and segmenting the represented brain tissue proximate the identified region of interest using a region-growing technique based on the identified region of interest.

Description of drawings

Fig. 1 is a flow chart of steps involved in a technique for segmenting the Sylvian Fissure, as described herein.

Fig. 2 is an image that indicates automatic seed selection. The dotted line passes the AC and is orthogonal to the midsagittal line.

Fig. 3 is an image of restrictions to avoid region growing going far from Sylvian Fissure.

Fig. 4A is an image of the skeleton of the Sylvian sulcal basin, and **Fig. 4B** is an image of the SF of a coronal slice.

Figs. 5A to 5E are respectively **(5A)** an original axial slice of a dataset, **(5B)** the central sulcal basin of the same axial slice, **(5C)** the skeleton, **(5D)** the cerebrospinal fluid, and **(5E)** the central sulcus of this axial slice.

Fig. 6 is a schematic representation of a computer system suitable for performing the techniques described herein.

Detailed description

The described technique involves five steps: reformatting, preprocessing, preliminary brain tissue segmentation, seed identification and sulcal basin segmentation, and CS/SF segmentation. Each of these steps is described in further detail below.

Step 1 *Reformatting*

First, one computes the midsagittal plane (MSP) and the three-dimensional (3D) coordinates of the anterior commissure (AC) and the posterior commissure (PC) for the input of a magnetic resonance image (MRI) volume. The dataset is reformatted so that the following conditions (a) to (d) are met:

- (a) the new X-axis has the same direction as the normal vector of the MSP;
- (b) the new Y-axis has the same direction as the line connecting the AC and PC;
- (c) the new Z-axis has the same direction as the vector product of the new X- and Y-axes; and
- (d) the volume pixel (voxel) sizes in X-, Y-, and Z-axes are all 1 mm, and the gray level at each voxel can be calculated using linear interpolation from the gray levels of the original dataset.

Step 2 *Preprocessing*

The scalp/skull is removed from the image via thresholding and morphological operations.

Step 3 *Preliminary brain tissue segmentation*

Statistics relating to brain tissue (such as mean value and standard deviation) are obtained for use in later steps. The image derived as a result of **step 2** is segmented using the fuzzy c-means method for the SF segmentation, and using thresholding combined with morphological processing for CS segmentation.

For the segmentation of both SF and CS, the brain tissues are classified into cerebrospinal fluid (CSF), gray matter (GM) and white matter (WM). Information about both the CSF

and GM is used to segment the sulcal basin in the next step. And CSF information is further used for final segmentation of SF and CS in **step 5**, described below.

Step 4 *Seed identification and sulcal basin segmentation*

For SF segmentation, the **step 4** starts from the coronal section containing the AC, because in this slice the SF section is well Y-shaped. Further, if one makes a line through and orthogonal to the mid-sagittal line (which could be taken as the intersection of the MSP and the current coronal slice), this line also goes through the SF as well.

Two seeds in SF can be selected from the dotted line in **Fig. 2**. The region of interest (ROI) is determined as follows. The right boundary is defined by a line which is parallel to the mid-sagittal line. The distance of the right boundary to the mid-sagittal line is equal to the distance to the left extent of brain mask, as indicated in **Fig. 3**. The same restriction is applied to the right SF in **Fig. 2** as well. This is based on the anatomical knowledge of interior extension of the SF.

After the region is extracted in the coronal section containing the AC, the sulcal basin of GM and CSF in the SF is extracted by the region growing technique, which uses the CSF and GM information from the preliminary segmentation of **step 3**. And seed points for other slices are automatically selected based on an extracted 2D region for its neighbouring slices.

For CS segmentation, **step 4** includes determining the region of interest (ROI) and reference slice, by 3D region growing, and taking the sulcal basin with the maximum volume as the central sulcal basin.

The 3D ROI has the following extension: X from the leftmost cortical point to the rightmost cortical point of the axial slice passing through the AC and PC, Y from y_{AC} to $y_{PC} + 30\text{mm}$ (where AC and PC's co-ordinates are denoted as (x_{AC}, y_{AC}, z_{AC}) and (x_{PC}, y_{PC}, z_{PC})), Z from the first axial slice with cortex (denote the z coordinate of this axial slice as z_0) to z_{AC} . The z co-ordinate of the reference axial slice is $5/6 \times z_{AC} + 1/6 \times z_0$.

Assume the MSP equation is $x = x_{MSP}$, where x_{MSP} is a positive constant. In the reference axial slice, 2 lines $x_1 = x_{MSP} + 15$ and $x_2 = x_{MPS} - 15$ are drawn. There are several intersected CSF/GM voxels with these 2 lines between (and near) AC and PC. Set these CSF/GM voxels as the seeds for 3D region growing to find their sulcal basin volumes. The sulcal basin with the maximum volume is the central sulcal basin.

Step 5 *CS or SF segmentation*

The skeleton of the central/Sylvian sulcal basin is obtained through two-dimensional (2D) skeletonization of the central/sylvian sulcal basin of the axial/coronal slice within the ROI. This skeletonization can be achieved through any existing 2D skeletonization method. **Fig. 5C** shows the skeleton of the **Fig. 5B**.

The CSF of the central sulcal basin is calculated through thresholding while the CSF of the sylvian sulcal basin is located through voxel membership function with the consideration of the almost constant thickness (there is variation across different regions) of cortices. **Fig. 4A** shows the skeleton of the sulcal basin in the SF. The SF is the union of the skeleton and the CSF voxels, which are from the preliminary segmentation of **step 3**, connected to the skeleton of the sulcal basin, as indicated in **Fig. 4B**.

Fig. 5D shows the CSF of the axial slice. The CS is the union of the skeleton and the CSF voxels connected to the skeleton of the central sulcal basin.

Computer hardware

Fig. 6 is a schematic representation of a computer system **600** of a type that is suitable for executing computer software for medical image processing as described herein. Computer software executes under a suitable operating system installed on the computer system **600**, and may be thought of as comprising various software code means for achieving particular steps.

The components of the computer system **600** include a computer **620**, a keyboard **610** and mouse **615**, and a video display **690**. The computer **620** includes a processor **640**, a

memory **650**, input/output (I/O) interfaces **660**, **665**, a video interface **645**, and a storage device **655**.

The processor **640** is a central processing unit (CPU) that executes the operating system and the computer software executing under the operating system. The memory **650** includes random access memory (RAM) and read-only memory (ROM), and is used under direction of the processor **640**.

The video interface **645** is connected to video display **690** and provides video signals for display on the video display **690**. User input to operate the computer **620** is provided from the keyboard **610** and mouse **615**. The storage device **655** can include a disk drive or any other suitable storage medium.

Each of the components of the computer **620** is connected to an internal bus **630** that includes data, address, and control buses, to allow components of the computer **620** to communicate with each other via the bus **630**.

The computer system **600** can be connected to one or more other similar computers via a input/output (I/O) interface **665** using a communication channel **685** to a network, represented as the Internet **680**.

The computer software may be recorded on a portable storage medium, in which case, the computer software program is accessed by the computer system **600** from the storage device **655**. Alternatively, the computer software can be accessed directly from the Internet **680** by the computer **620**. In either case, a user can interact with the computer system **600** using the keyboard **610** and mouse **615** to operate the programmed computer software executing on the computer **620**.

Other configurations or types of computer systems can be equally well used to execute computer software that assists in implementing the techniques described herein.

Conclusion

Various alterations and modifications can be made to the techniques and arrangements described herein, as would be apparent to one skilled in the relevant art.

CLAIMS

The claims defining the invention are as follows:

1. An automated method of segmenting the central sulcus and Sylvian Fissure regions in magnetic resonance image (MRI) image data representing brain tissue, comprising:

reformatting said MRI image data representing brain tissue to a predetermined spatial orientation dependent upon the midsagittal plane, the anterior commissure and the posterior commissure;

determining spatial statistics relating to spatial features of the represented brain tissue;

classifying the represented brain tissue within categories of white matter, gray matter and cerebrospinal fluid;

identifying a region of interest in the represented brain tissue classified as cerebrospinal fluid based on anatomical knowledge of the Sylvian Fissure and the Central Sulcus; and

segmenting the represented brain tissue proximate the identified region of interest using a region-growing technique based on the identified region of interest.

2. The method as claimed in claim 1, wherein the predetermined spatial orientation defines three orthogonal axes that are (i) a normal vector to the midsagittal plane, (ii) a parallel vector to the line segment connecting the anterior commissure and the posterior commissure, and (iii) a vector product of the axes (i) and (ii).

3. The method as claimed in claim 1, further comprising the step of identifying the central sulcal basin as the sulcal basin having maximum volume.

4. The method as claimed in claim 1, further comprising the step of identifying the Sylvian sulcal basin as the sulcal basin from the coronal section passing the anterior commissure where the basin is connected to the skeleton of the sulcal basin.

5. The method as claimed in claim 4, further comprising the step of obtaining the skeleton of the central/Sylvian sulcal basin.

6. The method as claimed in claim 1, further comprising the step of reformatting the image data to a predetermined spatial scale.

7. The method as claimed in claim 1, wherein the predetermined spatial scale defines a dimension of 1 mm along each of the orthogonal axes of each voxel.

8. The method as claimed in claim 1, further comprising the step of preprocessing the image data to remove bone and scalp tissue from the image.

9. The method as claimed in claim 8, further comprising the steps of preliminary Sylvian Fissure segmentation and preliminary Central Sulcus segmentation.

10. A computer program product for segmenting the central sulcus and Sylvian Fissure regions in an image of a brain comprising computer software recorded on a computer-readable medium for performing the method as claimed in any one of claims 1 to 9.

11. A computer system for segmenting the central sulcus and Sylvian Fissure regions in an image of a brain comprising computer software recorded on a computer-readable medium for performing the method as claimed in any one of claims 1 to 9.