Efficient Representation of Cortical Convolutions for the Analysis of Brain Surface Topology

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Abstract Various time efficient procedures were developed allowing to calculate planar representations of the brain in MR and CT clearly conveying the whole surface topology. For the comparison of the provided techniques we present additional complex functionality for the transformation of cortical convolutions between different representations after extracting and marking them manually or automatically. This includes re–projection to the original volume data in order to compare our approach to results obtained with direct volume rendering. Considering brain information exclusively, and ensuring a standardized orientation for the inter–patient comparison different segmentation and registration procedures are provided for the pre–processing. All implementation was integrated in a flexible and modular extensible platform allowing for convenient manipulation and visualization.

Keywords: cortical convolutions, visualization, segmentation, registration

1 Introduction

Medical image data from different 3D modalities like MR, CT and PET provide excellent representation of various parameters of the brain. Using anatomical and functional information brain areas are localized and related to specific functionality. Since most of these areas are part of the cerebral cortex which contains the gray brain matter, the efficient anatomical localization and meaningful visualization of the cortical convolutions is fundamental for analyzing morphological and functional information of the brain. In neuro–science it allows to examine physiological processes. In medicine it allows to understand the source and the effect of diseases if the affected convolutions and their related brain functions are identified. Additionally, the analysis of the topology and the size of convolutions can be used for a comparison of the left and the right hemisphere of the same individual or for a comparison of corresponding convolutions of different individuals.

Using tomographic slice images exclusively it is impossible to identify specific convolutions exactly. Therefore, contour lines are extracted in [1] using a 2D segmentation technique in order to reconstruct the brain surface. However, in case of volume rendering, the inspection of the whole brain surface is affected by the curvature of the cerebral cortex. Consequently, a planar representation was suggested in [2] using interior and exterior forces of a complex 3D network that models the brain surface. In order to prevent distortions which are caused by the projection, the network is appropriately cut open. Applying a similar approach according to [3], these irregularities are avoided by mapping the brain surface onto a sphere. Contrary to these time consuming techniques a more practical approach is presented in [4]. Based on dynamic programming and a slice oriented erosion procedure the relative brain surface is obtain which allows for fast visualization of the cortical convolutions in views of standardized orientation. Aiming at an intra– and inter–patient comparison of the brain hemispheres, we propose different approaches which allow for fast visualization of planar representations.

2 Segmentation and Registration

The calculation of the planar representations requires the segmentation of the brain volume. Two different approaches of volume growing are provided. Using a straight forward technique all voxels with gray values between a lower and a higher threshold are selected. Starting from a specific seed point within a user–defined volume of interest, they form a single coherent volume. Alternatively, a more sophisticated technique using a statistical process of voxel grouping [5], transforms the original image to a new gray value distribution. This allows for easy detection of the desired object by interactive thresholding. Ensuring an optimal segmentation, a diversity of tools is provided for user interaction. Finally, a registration procedure based on the a principal–axis method is applied in order to obtain a standardized orientation for the comparison of the left and the right hemisphere of the same or of different data sets [6].

3 Planar Representations

The principle idea of the presented approach is to unfold the brain surface in order to convey the cortical convolutions (gyri and sulci) simultaneously. Therefore, the global shape of the brain is transformed to an elementary geometric object while the local depth information of its surface is mapped to respective intensity values. Although a more complex geometry provides a better approximation, spheres and ellipsoids proved to be sufficient, and they are more convenient for the further processing. In particular, they are less time consuming with respect to the calculation of surface normals.

In order to extract the depth information the segmented brain surface is covered with a smooth envelop by closing its valleys with a small spherical filter. The surface normals of the geometric object then determine the direction of rays which are used to measure the distance between the envelop and the actual brain surface. After normalizing and applying a user–defined color look–up table the obtained values result in an image of the cortical convolutions on the surface of the geometric object. The final mapping to a planar representation inevitably causes distortions. Their location vary considerably depending on the applied technique.

If a *stereo-scopic spherical projection* is used both hemispheres are mapped separately. Linear rays are cast from the center of projection which transform every surface point directly onto the target plane. Starting from its center, which is mapped accurately, the distortion increases radially. Alternatively, a spherical parameterization allows to roll a sphere by 2π along a specified equator. In order to map the surface points to the plane it is additionally rolled $\pi/2$ perpendicular to the direction of the equator for every step. Distortions affiliated with this approach increase proportional to the distance from the equator.

Using *parallel projection* the surface is mapped onto opposite planes of a enclosing bounding–box. Since it does not aim at mapping the whole surface to a planar representation, there are only perspective distortions.

The *cylindrical projection* requires to project the depth information radially onto the surface of a cylinder object containing the brain. Similar to the unrolled spherical approach the geometric object is rotated by 2π around the longitudinal axis. The resulting images then show the whole brain surface topology since the information of the cylinder surface easily maps to the plane. Again, perspective distortions increase in directions perpendicular to the rotation axis.

4 Analysis of Cortical Convolutions

All methods provided for the segmentation, registration and visualization are combined in *SegMed* which represents a modularly extensible platform for the manipulation of medical image data based on *X/Motif* , *C++* and *OpenGL*. In order to allow for intra– or inter–patient comparison it provides multiple projections of one or more brain volumes with standardized orientation (see section 2). For a fast and convenient localization of cortical convolutions there is an extensive functionality of manual editing tools and a variety of adapted algorithms for automatic skeletonizing.

If manual identification of the cortical convolutions is selected it is possible to insert and manipulate an arbitrary number of vertices which are linearly connected. During the course of the analysis the resulting polygons are transformed on–the–fly between all planar representations. Optionally, they are re–projected to the original volume data in order to allow for a visualization with indirect and direct volume rendering. In order to obtain the center–lines automatically, different adapted thinning procedures [7, 8, 9] are provided. Since the quality of the results is related to the amount of noise inherent to the input images, a median filter is applied initially.

5 Results and Discussion

In order to obtain a comprehensive understanding of the cortical convolutions efficient techniques are provided which transform the whole brain surface to a concatenated planar representation. As an advantage of our approach related distortions are compensated using different projection techniques simultaneously presented in multiple windows with standardized orientation (Figure 1). They are interconnected with an extensive functionality for the localization of the gyri and sulci which encourages the intra– and inter–patient comparison. Aiming at practical applications efficiency is an important issue. Therefore, spheres, ellipsoids and cylinders were considered exclusively which allow for a fast calculation of the surface normals. The development of a fully automatic and fast segmentation procedure was beyond the scope of this work. Hence, manual correction is still necessary at this stage.

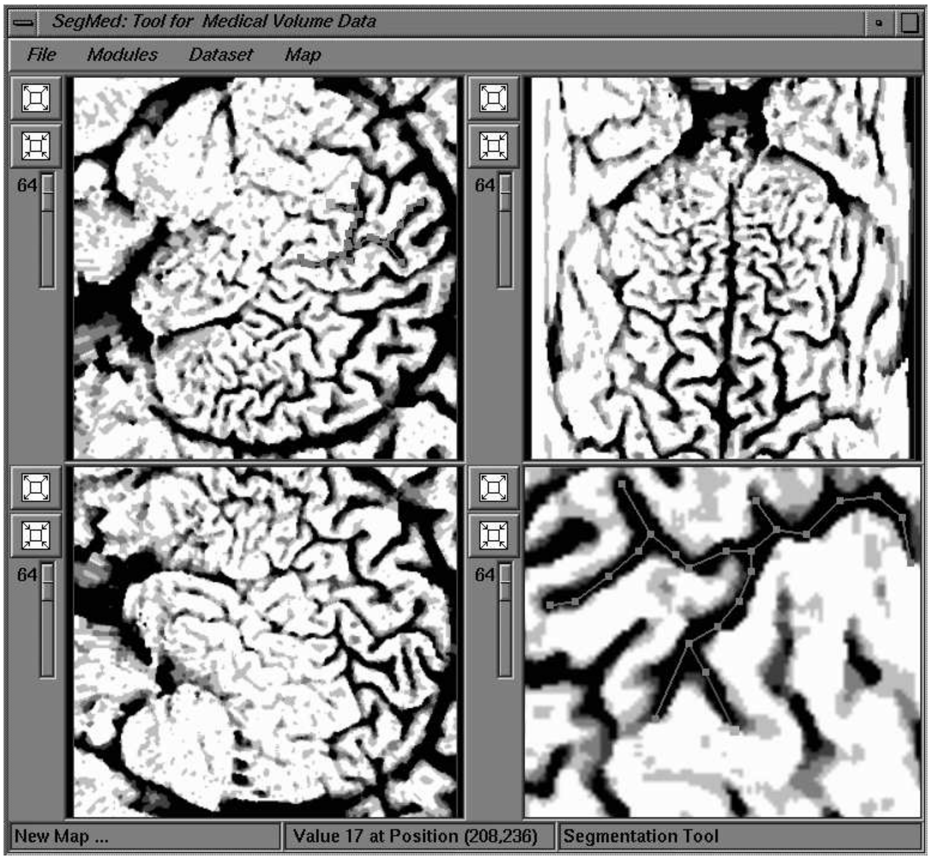

Figure1. Projection of brain: (left column) stereo–scopic spherical showing both hemispheres — (right column) unrolled spherical of front and back including manually inserted markers (right bottom) used for the identification of convolutions .

6 Conclusion

Several approaches are proposed which efficiently produce planar representations of the brain surface allowing for a convenient analysis of the cortical convolutions. For the evaluation of the available modules in practice they are transferred to a clinical environment in the near future. Further developments will mainly focus on accelerating the segmentation procedure required for the delineation of the brain volume.

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