Dealing with Inaccuracies in Multimodal Neurosurgical Planning – A Preliminary Concept

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Purpose:

MR based imaging of the head allows detailed insight into a variety of anatomical, structural and functional properties of the brain. MR contrasts like T1, T2 and FLAIR are the first choice for diagnosis and treatment planning in neuro-oncologic diseases. Diffusion and perfusion weighted images have also become well established standard sequences. Functional MRI and diffusion tensor imaging have passed research stages and entered clinical routine for cases where an added value of such images is expected. Current developments in software assistants for neurosurgical planning show a tendency to allow merging of all these images and corresponding analysis techniques – for good reasons. Since all images reveal different aspects of the same anatomic structure, the amount of information that can be gained from combined analysis of such images is significantly higher than just the sum of its contributors. However, none of these techniques is free of problems, which when combined sum up in a similar fashion the information does. Such problems are well known in the scientific communities dealing with these topics. However, a practicing physician cannot be equally aware of all these aspects while at the same time focusing on his primary task – helping the patient. This circumstance is accentuated by the fact that high quality graphical representations of combined processing results visually create a false impression of certainty and correctness about the data. This makes it hard for the surgeon or radiologist to rely on his personal assessment of a case, even if he is aware of potential quality issues.

For these reasons, one essential task of software assistants for surgical planning is to actively support the clinician in recognizing and avoiding existing traps and pitfalls, with the ultimate goal of preventing the patient from avoidable impairment. In this article, we present a combination of three concepts that demonstrate how this can be accomplished.

Methods:

To prevent misjudgment of a situation caused by inaccurate algorithmic results, we have developed a concept for workflow support that consists of three stages. Since a lot of time consuming preprocessing can be performed without user interaction, the first stage runs fully automated in the background. User interaction starts in the second stage, which consists of efficient but obligatory quality checks enforcing the physician to review and possibly edit preprocessing results. We have implemented special tools that support these quality checks, e.g. mosaic views and outline views for checking registration results or animated review of raw fMRI data for estimating intra-sequence motion and its correction before performing functional analysis. Datasets that do not fulfill certain quality requirements must be rejected to prevent misinterpretation caused by insufficient data quality. Finally, the third stage serves a planning purpose. Our concept offers customizable hangings, which correspond to individual setups of tools and viewers adapted to specific scenarios. Stepping through these hangings in a predefined manner actively supports the physician's awareness of potential hazards.

Fiber-tracking based reconstructions of white matter tracts are known to underestimate the underlying anatomic structures. A simple yet effective way to deal with this issue is the application of security margins of a fixed width around the reconstructed tracts, which are rendered semi-transparently over the actual fibers. Since such a representation again creates the false impression of accurately defined borders of the fiber tracts, we propose a novel technique for rendering security margins based on direct volume rendering. In a first step, the reconstructed fibers are voxelized into an isotropic grid, on which a Euclidean distance transformation is applied afterwards. This yields a 3d image where each voxel's value encodes the minimum distance to a reconstructed fiber. When rendering this image, a lookup table for voxel-transparencies is applied which increases transparency for high valued (= high distance) voxels, resulting in a security margin representation that fades out smoothly the further it departs from the fiber. The width of this margin can now be modified interactively by simply editing parameters of the lookup table. A further step within the proposed concept is to compute a data based uncertainty measure in analogy to a probabilistic tracking scheme.

The standard and widely accepted method for analyzing fMRI studies is the general linear model (GLM), which is a statistical method capable of detecting and matching temporal relationships in the data with a model given by the experimental setup. In most fMRI experiments, spatial accuracy is not a main concern and heavy blurring or smoothing is applied to facilitate statistical analyses, e.g., to find differences between patients and healthy controls. However, for surgical planning, good spatial delineation of critical functional areas is crucial. The traditional smoothing applied in fMRI analysis is an example of model based inaccuracies that induce problems to the process of planning. To mitigate this problem, we have developed and implemented a new adaptive approach for the analysis of fMRI data which is capable of detecting homogenous spatial regions of activation in addition to showing increased sensibility and spatial accuracy.

Results:

The proposed methods have been integrated into a software assistant for neurosurgical planning. Workflow support is realized through automated preprocessing pipelines, obligatory quality checks, and a hanging-concept that automatically selects predefined viewers and tools depending on the data available for a case. This is in strict contrast to widely used random access schemes for organizing software functionality and tools, which are often complex and inefficient to use. A novel method for visualizing inevitable uncertainty of fiber-tracking results has been developed and included in our application.

Conclusion:

The proposed concepts and methods represent a preliminary approach for dealing with data and model related problems faced in multimodal neurosurgical planning. We consider this approach as the minimum level that any neurosurgical planning system should provide. In current systems, the crucial aspect of alerting the user to data and model inaccuracies has often been disregarded. Further investigations are necessary to determine the amount of individual contribution of the different influencing factors to neurosurgical decision making. We are currently in the process of designing a set of adequate questionnaires for specific methodological aspects and surgical situations.