Brain Virtual Dissection and White Matter 3D Visualization

Barthélemy SERRES[a,b,1], Ilyess ZEMMOURA[b], Frédéric ANDERSSON[b],
Clovis TAUBER[b], Christophe DESTRIEUX[b] Gilles VENTURINI[a]

[a] *Computer Science lab, EA 6300, University François Rabelais, Tours, France*
[b] *UMRS INSERM U930 – University François Rabelais, Tours, France*

Abstract. This paper presents an immersive visualization tool that helps anatomists to establish a ground truth for brain white matter fiber bundles. Each step of a progressive anatomical dissection of human brain hemisphere is acquired using a high resolution 3D laser scanner and a photographic device. Each resulting surface is textured with a high resolution image and registered into a common 3D space using fiducial landmarks. Surfaces can be visualized using stereoscopic hardware and are interactively selectable. The tool allows the user to identify specific fiber bundle parts. Extracted fiber bundles are stacked together and rendered in stereoscopy with the corresponding MR volume. Surgeons have validated this tool for creating ground truth in medical imaging with the perspective of validating tractography algorithms.

Keywords. 3D Laser Acquisition, Interactive segmentation, Stereoscopic Visualization, Fiber bundles reconstruction

Introduction

Current medical imaging techniques (CT scanner, MRI) make it possible to acquire 3D volume data of the body and to study specific substructures. To do so, pattern recognition methods can be used to objectively segment or classify the images. However, the validation of such methods usually requires the knowledge of ground truth, which is not always available. While physical or numerical phantoms can be used as a first validation step, it is often necessary to further validate the method on real sample images. Building digital ground truth from a real specimen is a challenging task in medical imaging. The work presented in this paper is in the context of the validation of tractography algorithms, which reconstruct in 3D white mater (WM) fiber bundles from diffusion MRI raw data [1]. Building a ground truth in this domain requires 1) the acquisition of data with a high precision in order to obtain, at the end of the process, a ground truth with the highest possible accuracy, 2) a 3D visualization and selection methods for the identification of specific substructures, 3) an overall 3D visualization of the resulting ground truth for its visual validation. In this paper, we will describe point 1) and we will show how Virtual Reality (VR) can be used for points 2) and 3).

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[1] Corresponding Author.

1. Material And Methods

1.1. Data acquisition and preprocessing

Methods used in tractography take as input a diffusion MRI and output the detected fibers bundles [2]. In order to define, for such approaches, a ground truth based on the brain real anatomy, we had to use a different modality for the acquisition of data. We have therefore conceived a destructive acquisition process based on the dissection of the brain. At each dissection step, the anatomist acquires the 3D surface of the specimen as well as a photograph that is mapped onto the surface, which becomes textured. These steps are repeated until the whole brain has been dissected. The result of this process is a set of textured surfaces that are registered using fiducial landmarks.

More precisely, the brain, previously prepared with Klingler's method [3], is fixed on a small platform. This platform has fiducial landmarks that can be both detected with the laser head and within an MRI. Then, the anatomist performs the dissection, step by step. At each dissection step, he acquires the brain surface (with a laser scanner), the fiducial landmarks (with the scanner probe) and an ortho-photograph of the surface. These steps are repeated until the whole brain has been dissected.

After this acquisition process, the data is pre-processed with no loss of accuracy (250 μm with the laser scanner): all degenerated, isolated and non-manifold triangles are removed. Then, surfaces must be registered using the four fiducial and non coplanar landmarks located on the edge of the acquisition platform. Acquired surfaces are registered onto the first acquired surface (reference) using the ICP algorithm [4].

1.2. Visualization and interactive selection in Virtual Reality

After data acquisition and pre-processing, the anatomist must visualize the acquired data in order to select and label regions of interest (ROIs). ROIs with the same label are further used to reconstruct a given substructure of the brain in 3D.

Several approaches have been developed for the visualization of WM bundles, mainly in the context of reconstructed fibers from MRI tractography algorithms. An early work that deals with white fibers bundles polygon rendering is for instance [5] where these structures are rendered using stream tubes and stream surfaces. Recent work proposed a technique based on DTI results, with a hybrid visualization method of WM using triangles and point-based rendering [6]. Thanks to the graphics hardware improvements, the rendering possibilities have dramatically increased and have allowed the representation of fibers within a volumic context. Examples of such techniques also involve volume rendering with clipping boxes [7] or image fusion [8]. Concerning the immersive visualization, we mention the use of immersive CAVE setup [9] where fiber tracts are presented to experts. Such an installation can provide a good immersion feeling, but is expensive and non-portable.

Our goal is to design an interface for exploring the acquired surfaces, which includes data importation, texturing tools, surfaces 3D visualization, and navigation. We have designed a selection tool to be specifically used by the anatomist while proceeding to the selection and labeling step. Selection on meshes is needed to create ROIs. Using this tool, the expert can draw directly onto the surface to label the boundaries of the region of interest, and can automatically fill in the closed region to obtain a complete selection of the ROI. "Select" and "unselect" commands provide the anatomist a fine tuned control of the labeling process.
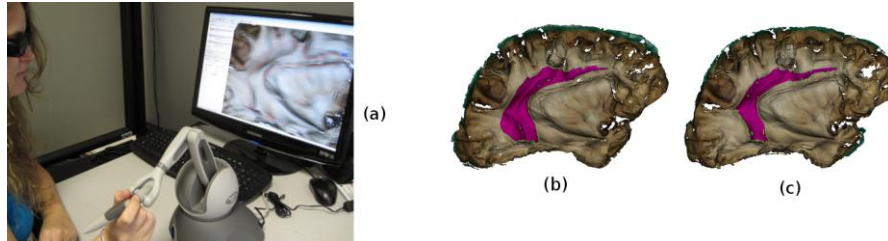
Figure 1. Selection task – (a) VR setup with stereo display and haptic feedback. (b) (c) 2 digitized hemisphere brain surfaces, representing 2 successive dissection steps of the total 10. In purple, we can see expert-highlighted SLF parts identified on each dissection.
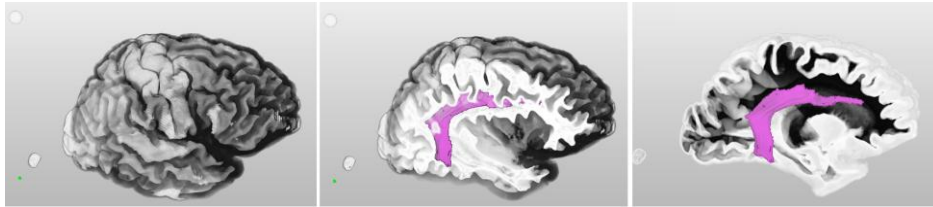

Figure 2. SLF reconstruction visualized in the volumic context. The cutter tool consist of freely moving a cutting plane among the volume to let fiber bundles reconstructions appears. This makes the anatomist explore connexions with others brain parts, like other bundles, but also cortical or sub-cortical areas.

The proposed tool includes a haptic device, the Phantom Omni **[10]**, allowing the anatomist to move a 3D cursor onto the surface (see Figure 1(a)). This 3D cursor is sliding on the surface and makes the anatomist feel the relief. A snap distance is set to create an attraction force as the cursor flows closely to the surfaces. This force also ensures that the cursor stays onto the surface during labeling. In order to enhance the immersion of the user, textured surfaces are displayed with stereoscopic hardware (120Hz LCD screen with shuttering glasses). This makes the anatomist closer to his usual working conditions, i.e. under stereo-microscopic magnification.

1.3. Visual validation of substructures: combining surfaces and volumes

After the selection of several parts of a substructure, the anatomist must check that these parts are relevant and that no errors occurred. This step is necessary in order to validate the discovered substructures. For this validation procedure, our tool proposes a visualization of the selected surfaces within a volumic representation of the brain that consists in an MRI of the brain acquired before the dissection. As described in section 1.1, fiducial landmarks are also detected in the MRI and used to register the surfaces onto the MRI, using the ICP algorithm. It is then possible to represent the surfaces within the brain volume (see Figure 2). Our method provides the expert with a visual validation tool, called virtual cutter. This tool makes it possible to freely move a virtual cutting plane in the data, uncovering global context of the MRI acquisition. This helps the anatomist to point out connections between the labeled structure and its surrounding. This task is performed by our expert inside our immersive visualization.
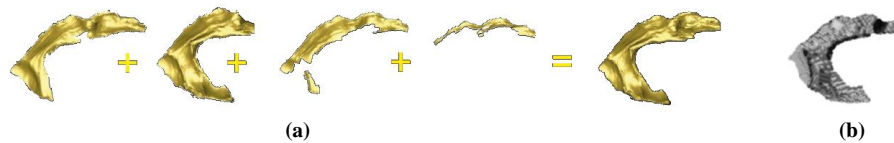
(a)   **(b)**

Figure 3 : (a) Multiple surfaces labeled parts, allow the 3D reconstruction of the targeted substructure (Surfacic Rendering). (b) Shows the voxelized version of the reconstruction result (Volume Rendering).

1.4. Ground Truth 3D Reconstruction from surfaces

Once the different parts of a substructure are selected and labeled in the surfaces, a volume can be reconstructed (see Figure 3) and further used to validate pattern recognition methods. For generating this volume, the user selects the desired output resolution in voxels. Then, a sampling is performed: in the output image, each voxel which has a non zero intersection with the labeled parts of surfaces is set to "1", and all other voxels are set to "0". In order to avoid empty spaces between surfaces, we artificially increase the number of triangles in the surfaces by sub-sampling techniques. The output volume can be represented in any standard volumic visualization software and can be used to validate pattern recognition methods.

2. Results

We have applied our technique to a brain hemisphere with the objective of reconstructing the Superior Longitudinal Fasciculus (SLF). Our aim was also to obtain a formative feedback from experts. The brain was prepared and fixed in our platform. After the MRI acquisition, the anatomist (neurosurgeon) has performed the iterative dissection and acquisition process. Dissection lasted one day. Then all surfaces and their corresponding textures were loaded into our software that can handle very large meshes (>3 Millions faces). Textured triangle meshes were displayed at interactive frame rate (above 25 frames per second) and the anatomist was able to freely navigate through the different dissection steps. Surfaces were accurately registered together using the detected fiducial landmarks (surfaces registration error < 0.3 mm). The anatomist has identified, on each surface, the SLF bundle parts (see Figure 1(b,c)). Then the labeled parts of surfaces were used to reconstruct the SLF in 3D (see Figure 3). The expert has used the combined surfacic-volumic visualization to finally validate the reconstructed object. He was satisfied with the results.

The expert feedback was as follows. First we gave the anatomist an overview of the proposed software and interface, including the use of 3D stereoscopy and the haptic device. The user interface was considered as intuitive and well organized. The anatomist managed to achieve the knowledge extraction task (i.e. the ROI selection task on every digitized dissection step) in a short time, approximately 15 minutes. We have asked the expert about his opinion on the use of VR and haptic devices. Haptic set up gave the expert a good global perception of the surface to be explored. However, surfaces with holes caused sudden changes of the feedback forces and could punctually alter the immersion feeling. In a second evaluation step, we have asked four other experts to use our interface for solving the ROI selection task (with the same SLF surfaces), and we have used a post-task questionnaire to obtain their evaluations. The results were as follows: 3 experts were satisfied with the tool, and have not suggested

improvements. One expert highlighted also difficulties with the haptic feedback and requested for a longer training step. Due to particular bundle shape, haptic feedback may give useful railing constraints for the selection task, avoiding false-positive selection.

3. Conclusion & Discussion

We have presented a tool that makes it possible to create ground truth for medical imaging from dissection, with a first application in the context of WM reconstruction. We have defined an acquisition procedure, and tools for data preprocessing. We have given anatomists the opportunity to interactively "replay" the dissection and browse the dissection steps through an immersive setup. Our software has been designed to label any kind of substructure parts, visible on the different dissection steps, using a force feedback haptic device. To add depth perception, the working scene has been displayed using stereoscopic-enabled hardware. Collected parts on the different surfaces acquired during anatomical progressive dissection make it possible to reconstruct 3D models of the studied structures, and to visualize these models in 3D within a volumic context.

We have presented an application of our technique in the specific case of human brain dissection for WM retrieval. One of the significant fiber bundles, the SLF has been dissected by an anatomist and reconstructed, producing a 3D model. The experts have visualized the SLF reconstruction result in its MR T1 volume context, and were satisfied by the results. Our software is currently used in a clinical research protocol to create further ground truth of WM fibers bundles from different specimens.

The next step in this work consists in defining a protocol for comparing the obtained ground truth volumes with WM tracts detected with tractography algorithms. A further study with many more specimens will result in an expert validated atlas of white fibers, along with the corresponding diffusion MRI, thus providing the research community with a complete framework for tractography algorithms validation.

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