Acquisition and Interactive 3D Exploration of the Internal Structure of a Dissected Specimen

B. Serres*, I. Zemmoura°•, C. Destrieux°•, F. Andersson•, C. Tauber**, G. Venturini*

Abstract— **We present a system to keep track of a destructive process such as a medical specimen dissection, from data acquisition to interactive and immersive visualization, in order to build ground truth models. Acquisition is a two-step process, first involving a 3D laser scanner to get a 3D surface, and then a high resolution camera for capturing the texture. This acquisition process is repeated at each step of the dissection, depending on the expected accuracy and the specific objects to be studied. Thanks to fiducial markers, surfaces are registered on each others. Experts can then explore data using interaction hardware in an immersive 3D visualization. An interactive labeling tool is provided to the anatomist, in order to identify regions of interest on each acquired surface. 3D objects can then be reconstructed according to the selected surfaces. We aim to produce ground truths which for instance can be used to validate data acquired with MRI. The system is applied to the specific case of white fibers reconstruction in the human brain.**

I. INTRODUCTION

In this paper, we deal with the problem of modeling the internal structure of any solid object by the repeated acquisition of its 3D surface during its progressive "destruction". For instance in the medical field, the object can be a given organ, like the human brain, and its destruction corresponds to a step by step anatomical dissection. At each step of this dissection, a 3D surface can be acquired, and at the end of the dissection, a large number of surfaces can be used to reconstruct the 3D internal structure of the object. In addition, it is necessary to allow identification of inner 3D regions as they appear during the object destruction. In our example, such regions can be the brain inner structures, like groups of white matter fibers for instance. Then, these reconstructed structures can be used as a ground truth to validate other acquisition methods or other pattern recognition algorithms that are supposed to detect them. In our case, the ground truth will concern the white fibers in the brain, with the aim to use it in the future for the validation of tractography algorithms which are intended to detect such fibers from diffusion MRI [1] [2].

To reach this objective, we propose a novel method to : 1) perform iterative 3D acquisitions of the object's surface during dissection, 2) register the acquired surfaces, 3) visualize the surfaces with a stereoscopic and immersive display used by the expert to select and annotate regions of interest (ROI), 4) reconstruct inner structures in order to use them as a ground truth.

The remaining of this paper is organized as follows: section 2 describes the related work. Section 3 gives the main principles of our approach. Section 4 presents the first results which aim to validate the methodology. Section 5 concludes on this work and presents the possible perspectives.

II. RELATED APPROACHES

Access to the inner structure of anatomical specimens has been studied for years in Medicine. It has been studied thanks to dissection and multiple slices. Multiple slices aim to reconstruct a 3D object from multiple slices manually labeled by an expert in different ROI's. Since it reconstructs the whole volume of the specimen, interspecimen comparisons are possible [3]. This technique was routinely used for reconstruction of inner structures of embryos, but suffers from distortion induced by the slicing process. Moreover, some structures, for instance brain white matter fibers, are not easy to recognize or even to see on anatomical slices. Dissection provides a surfacic view of the specimen and progressively detects some anatomical structures while more superficially located ones are destructed as dissection progresses. Due to this destructive and surfacic approach, results of dissection are usually obtained in the laboratory anatomical space. Therefore, no quantitative comparison to other dissections and other techniques results was possible.

A possible alternative is the idea of recording 3D surfaces using 3D acquisition devices during dissection. Acquisition of 3D geometry by laser devices holds substantial promises as a technique for realizing such tasks. Although the use of 3D scanning devices were firstly dedicated to industrial applications, the literature describes many other research fields involving such a device. All these works are focused on accurate 3D surface acquisition. In the cultural world heritage, [4] worked on 3D digitalization of a historical temple located in Taiwan using a 3D laser scanner. In the medical field, while many are working on reconstruction [5], some others are working on volume comparison like [6] by acquiring anatomy using 3D laser scanner. We also mention [7] who demonstrated the utility of watching treatments evolution and [8] who used 3D laser scan for CT scan comparison and validation. Some others [9] work on creating ground truth data for the comparison of the morphological properties of the bone cartilage with those obtained with segmentation from MRI imaging. They described how they

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* LI, University François Rabelais of Tours, 37200 Tours, France {serres,venturini}@univ-tours.fr

○ Department of Medecine, 37000 Tours, France

• UMRS U930 Inserm / CNRS ERL3106 / University of Tours, 37000 Tours, France

** Physics and Mathematics Lab, University François Rabelais of Tours, 37000 Tours, France

managed to measure and compare cartilage volume computed from acquired 3D surfaces. They also compared their results to segmentation results obtained from MRI dataset.

The problem we deal with is a generalization of this last work where only two surfaces are acquired. Here we consider that one must keep track of a destructive process where many successive surfaces are involved, in order to reveal the inner structure of the object. This inner structure can be reconstructed from the surfaces obtained during the dissection, but this also requires a more advanced visualization and interactive tool because many surfaces can be involved in this process.

III. Proposed Method

A. Overview

Our work is focused on providing a method to reach these objectives in order to extract knowledge from the acquired 3D data. Starting from an object of interest (see figure 1), a progressive "dissection" is performed. A step in this dissection corresponds to the removal of a part of the object in a ROI (we assume that other steps, which consist in removing non interesting parts of the object, may not be considered). The ROI can be an inner structure represented by a volume inside the object, and the dissection process will progressively remove all parts of this ROI. Each removal is subject to a surface acquisition. Once such surfaces have been acquired, a pre-process can be performed to simplify the resulting meshes. Then the next step in our process consists in registering these surfaces in a common coordinates system. After that, the surfaces must be visualized in order to allow selection of surfaces subparts that correspond to ROIs. This selection may have to be done across several surfaces, because the ROI may have been removed during several dissection steps. Such selected surfaces are labeled for instance with the anatomical name of the ROI. Finally, the volume of the ROI can be reconstructed thanks to the selected registered sub-surfaces.

B. Surfaces Acquisition

1) Geometry Acquisition Device: The 3D surfaces geometries need to be accurately and easily acquired. We had to find a device which allows multi-viewpoint acquisition, in order to handle complex and rough objects, such as anatomical or plants structures. Moreover, the acquisition steps need to be focused on the structure of interest, this is why we need a laser scanner which is mounted on a 6-DOF articulated arm[1], see Figure 2. This device allows us to acquire any non transparent surfaces of our anatomic objects. Then, we need to acquire the texture.

2) Color Texture Acquisition and Mapping: The resolution of the acquired texture needs to be high enough in order to be as close as possible to the real visual aspect of the studied object and to provide the experts with enough information to accurately localize ROI's on 3D surfaces. This acquisition is performed using a standard camera[2] (Figure 2).

[1]Faro Laser ScanArm, FARO Technologies, USA
[2]K20 Pentax, Pentax Corporation, Japan

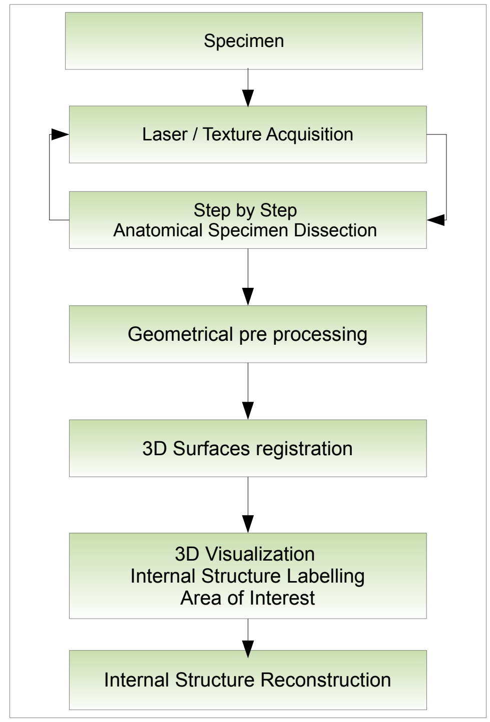


Fig. 1. Diagram of our method workflow

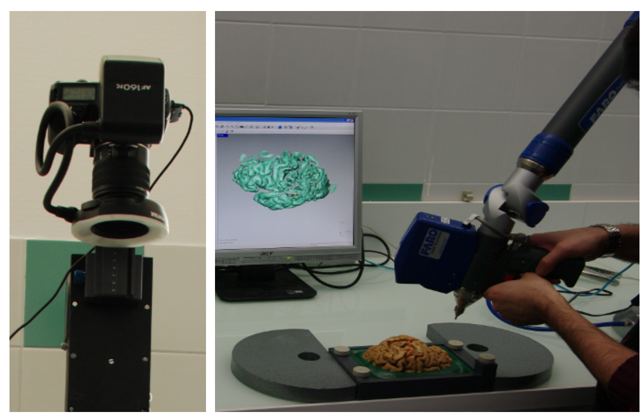


Fig. 2. Photographic device for texture acquisition and the laser scanner surface acquisition

High resolution images are acquired orthogonally to the area of interest. Indeed, the structures we are looking for are mainly on the X-Y plane, while dissection process takes place along the Z axis. We have been facing several constraints, such as reflections, shadows, and repeatability across successive dissection steps. We worked with a professional photographer to design the best lighting conditions which suits our needs (a ring located on the camera). Then this picture is mapped onto the laser surface. For this purpose, we use fiducial markers to find the 3D position of the camera w.r.t. the surface.

C. Surfaces Registration

Registering 3D surfaces is a crucial step in our method since it is mandatory for an accurate reconstruction of the object from multiple surfaces. Fiducial markers are spread onto the platine where the specimen is fixed to be dissected. These markers are designed to be acquired by the laser scanner contact sensor (Figure 3) before starting the acquisition process. The involved registering technique is rigid, every points are identically transformed.

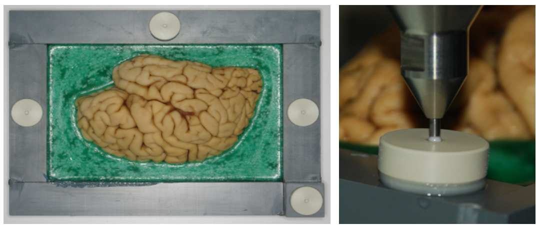


Fig. 3. Four markers are located onto the support and acquired by the scanner probe

D. Surfaces Visualization

The visualization need to be designed to bring optimal perception of the scene. That is why we choose to investigate the use of 3D stereoscopic techniques for the virtual scene display. Stereoscopic 3D displays increase the immersion feeling of users by providing an enhanced depth perception. Stereoscopic display used in our application is based on an IR-emitter, shutter glasses and a 120Hz-enabled screen. Moreover, we provide to the users a 3D pointer sliding over the surface in order to reinforce the user's immersion feeling. Indeed, this pointer also allows to track the user's eye focus point, insuring the comfortable and automatic adaptation of the focal plane. Several surfaces can be visualized at once. But, during the labellization process, the attention of the user should be focused on only one surface. That is why we choose to display the others surfaces with transparency. The user may switch from one surface to the next one, according to the order of acquisition during the dissection. So he may easily follow the destructive process.

E. Knowledge Extraction

Once we have the set of 3D textured surfaces registered and visualized, we need to provide to the expert a labeling tool. He will use this tool to label the areas corresponding to the internal structure he is looking for. We call areas of interest the subparts of a ROI, which are identified during the labeling process. This process is repeated on each surface and is divided in two tasks. First the expert selects the area of interest using a triangle selection tool. Then, as the expert validates the selection, he assigns a class to this area. This class is used to distinguish the different ROIs to be tracked.

1) Selection of an area of interest: This area is composed of triangles, which could be disjoint. These features allow a necessary flexibility in the identification and selection process. We have implemented three selection modes: rectangular region selection, segment based selection and free

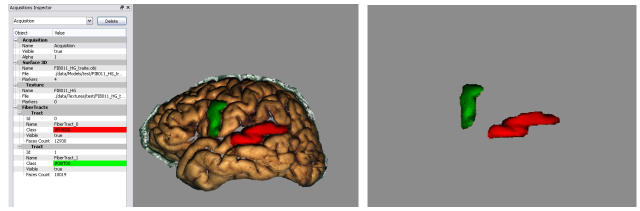


Fig. 4. Interactive tool provided to the expert to label the regions of interest

region selection. We also provide to the user two operators (selection union, selection inversion).

2) Labelization: Once the areas of interest have been selected, then the class assignment process can take place. Each area of interest is a valid selection of triangles which belongs to a ROI in the object and must therefore receive the class assignment that corresponds to this ROI. For each class i corresponds a color C_i which uniquely identifies this class. Each triangle from the area of interest is labeled and colored accordingly. One triangle belongs to only one area. During the annotation process, the user may hide the previously labeled areas in order to clarify the virtual scene (see figure 4).

IV. RESULTS

A. Evaluation of surface accuracy and registration

To setup the internal structure reconstruction process, we have experimented the surfaces registration step. We have built a test scene, composed of a simple known object, fixed on a rigid platine where four markers have been stuck. This scene is scanned with the laser on the first time, then slightly displaced, and acquired again. Then, we have two 3D surfaces of the same scene, but in a different position. We have tested three methods to register these surfaces. These registering methods are based on the ICP algorithm [10]. We have analyzed the different results of the registering methods. The first method takes the whole points cloud of the surfaces into account. The second method only uses a sub-surface (a selected subset of the whole points cloud), and the last one is based on the markers acquired by contact. We have measured an error distance, called positioning error. This error is computed for each point of both surfaces, using a nearest neighbors matching. Figure 5 shows the resulting measures we obtained.

We notice that taking the whole surface into account does not lead to correct registration. However, registrations based on user selected area, or on markers, lead to a much smaller measured error. Thus, we can conclude that these two registration methods are much more interesting. Indeed, more than 90% of the points show a registration error inferior to 0.5 mm. These registrations methods are both accurate, but the advantage of the markers based registration consists of the non user dependence (it is automatic). This ensures the repeatability of the process.

B. Anatomic Surfaces Acquisition And Distortion Evaluation

We tested our acquisition method onto anatomical specimens: brain hemispheres. Specimens were previously pre-

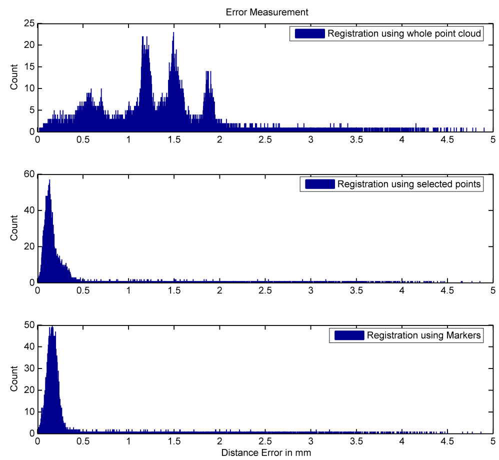
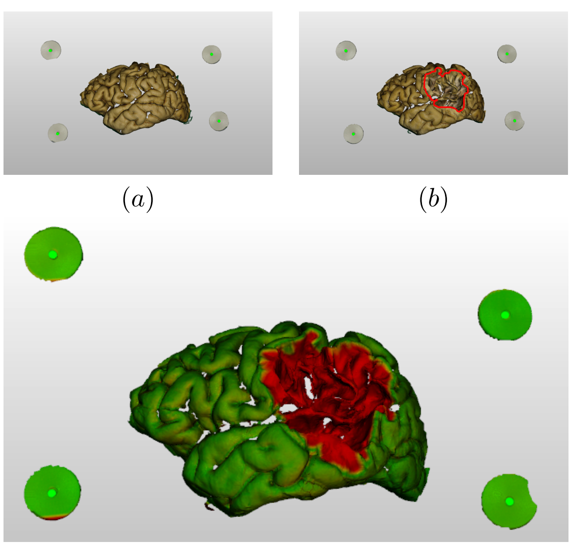


Fig. 5. Histograms showing the error dispersion of the three registration methods

pared for dissection and stuck with parafine on a support containing fiducial markers. Fibers tracts dissection is performed by a trained anatomist. We have acquired the surface of the same specimen at two different dissection states (Fig. 6a, and 6b). Data has been imported in our software in order to be visualized. The expert has found that the visualization was satisfactory especially for selecting areas of interest.



(c)

Fig. 6. Dissected surface (b) is registred on the original surface (a) and the resulting distortions are shown (c)

We also focused on the study of possible distortion of the surface during dissection, which could happen because of the multiple dissection steps. Figure 6c presents distortions between two consecutive dissection steps. Distortion is encoded from green to red color. The threshold for visualization was 0,5 mm. As expected, distortion was important in the dissected area. More interestingly, it was negligible outside the dissected area, showing that distortion of the specimen during dissection was negligible.

V. CONCLUSIONS AND FUTURE WORKS

We have developed a method to track a destructive process, such as a dissection, in order to reconstruct the internal structure of the dissected specimen. We have proposed an acquisition method based on a laser scanner for obtaining an accurate surface, and based also on a camera for high quality texturing. We have designed a 3D visualization of the surfaces in conjunction with an interactive labeling tool. Experts can easily visualize and classify internal structures on every acquired surfaces thanks to the attached texture information. We have shown that the accuracy of the surfaces and the registering process are satisfactory. We have checked that dissections do not create distortions on the specimen of interest (i.e. human brains).

The work that remains to be done now consists in generating a volume from the multiple labeled areas that corresponds to a ROI. We will explore wrapping methods [11][12] to allow the reconstruction of the tracked internal structure. After that, we will focus on comparing MRI tractography datasets to our results. The objective will be the validation of the MRI tractography algorithms.

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