3D Sketching on Interactively Unfolded Vascular Structures for Treatment Planning

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ABSTRACT

In clinical practice, sketches support physicians in treatment planning. For example, they are employed as direct annotations in medical image data. However, this approach leads to occlusions in case of spatially complex 3D representations of anatomical structures such as vascular systems. To overcome this limitation, we developed a framework which enables the physician to create annotations by freely sketching in 3D environment. We solve the problem of occlusions by an animated representation of the original and unfolded vascular structure with interactive unfolding. For this, we use a semi-immersive stereoscopic display and a stylus with ray-based interaction techniques.

Index Terms: I.3.6 [COMPUTER GRAPHICS]: Methodology and Techniques—Interaction techniques I.3.7 [COMPUTER GRAPHICS]: Three-Dimensional Graphics and Realism—Animation J.3 [LIFE AND MEDICAL SCIENCES]: Medical information systems

1 INTRODUCTION

In medical interventions, complicated cases require an intensive pre-operative planning regarding aspects such as spatial relationships, shape and volume [5]. This especially holds for cerebrovascular diseases, i.e., pathologies of blood vessels that supply the brain. For example, strong dilations of arteries (i.e. aneurysms) can rupture and cause a hemorrhage in the brain. These critical incidents have a fatality rate of 40% to 60% [1].

One instrument which supports physicians in treatment planning of cerebrovascular diseases is sketching. It is used to annotate important structures or describe access paths, e.g., by being directly drawn onto 2D image data in the workstation software [4]. This solution has limits in cases where spatially complex representations of vascular structures lead to occlusions of overlaying vessels.

To overcome these limitations, we present a framework which allows physicians to freely sketch annotations in 3D. We address the problem of occlusions and spatially branched vessels in 3D planning models with two approaches. First, we provide a representation of the folded and unfolded vascular structure with an interactive, seamless transition between these two states. The sketches are part of the 3D space and, thus, can be pinned to the animated vascular structures. Second, we support the physician with a stereoscopic display and a stylus with ray-based interaction techniques.

As a representative example for a complex anatomical structure, we chose the *Circle of Willis* (CoW). The CoW is the central part of the cerebral vessel system and supplies the brain and surrounding structures. It is well suited for sketched 3D annotations in a semi-immersive environment due to two reasons. First, it includes many different sub-structures, which are essential in neuroradiology, and second, the spatially complex vascular extents and transitions make it difficult to comprehend its real anatomical representation.

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2 RELATED WORK

Unfolding. Curved tubular structures, such as blood vessels, are of high interest in medicine. These are assessed with tomographic image data. However, the necessary information rarely lies in a single image plane, which motivates the unfolding of these structures. An established technique for this is Curved Planar Reformation (CPR) [2]. Here, the central axis of the tubular structure is derived from the tomographic data and used to map the structure into a new image providing its longitudinal view. To investigate the whole structure with this method, the visualization has to be rotated around the central axis. Vilanova et al. [7] unfold structures directly in the 3D view, which solves the problem of alternately investigate the 2D and 3D view. Our solution is based on this idea. However, we do not only use the unfolded structure, but allow the physician to seamlessly animate between the original and unfolded 3D representation in an interactive manner.
Sketching. In medicine, sketches are used in several areas. For example, they serve as an intuitive interaction technique for medical reports [4] or for the creation of 2D vascular structures with integrated blood flow [6]. Beneath 2D interfaces, sketches are used in immersive environments with spatial input. For example, Wesche and Seidel [8] realized the drawing of curves in virtual environments. Our work also allows the spatial creation of sketches in a semi-immersive environment.

3 MATERIAL

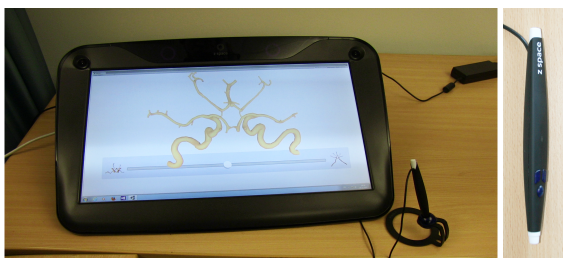
Reconstruction of the 3D Surface Mesh. We extracted a CoW from a healthy patient's MRI data with a voxel resolution of $.26mm \times .26mm \times .5mm$. Afterwards, we artificially generated a basilar aneurysm, which was approved by an interventional neuroradiologist. The 3D surface mesh was extracted with the rapid prototyping tool MeVisLab (Fraunhofer MEVIS, Bremen, Germany) by applying a threshold-based segmentation.
Unfolding of the Surface Mesh. The unfolding was realized with skeletal animation in 3ds Max (Autodesk, Inc., California, U.S.A). Here, the original surface mesh is provided with a skeleton represented by a set of interconnected bones. First, we attached the manually created skeletons to the reconstructed CoW. By assigning every vertex to one or multiple bones, the bones can be animated and the vertices are transformed accordingly. Second, we created an unfolded state with a combination of forward and inverse cinematics. Finally, the animation was created by interpolating between the original and unfolded state (see Fig. 1).

4 FRAMEWORK

Input and Output Device. We use the semi-immersive zSpace (zSpace Inc., San Francisco, U.S.A.) (see Fig. 2a). It realizes fish-tank VR with a stereoscopic display. The binocular parallax is

Figure 1: Animated unfolding of the Circle of Willis (left to right).

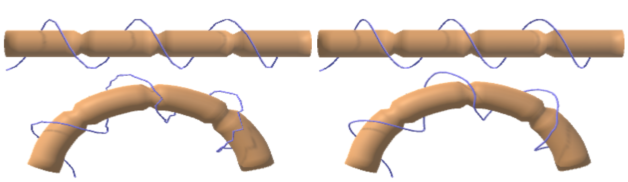
achieved with polarized rendered images for passive glasses and motion parallax through infrared (IR) markers on the glasses, which allows six degrees of freedom (6-DoF) head tracking. As input device, the zSpace's 6-DoF stylus is used, which is actively tracked with IR LEDs (see Fig. 2b). The stylus' orientation is virtually extended in the rendered scene represented with a visible ray.



(a) (b)

Figure 2: Our framework is implemented on the semi-immersive zSpace (a). A 6-DoF stylus is used for ray-based interaction (b).

Interaction Techniques. For translation, we use a ray-based interaction technique. After pressing the stylus' button, the position of the virtual ray tip is used to calculate the stylus' movement delta, which is applied to the object. Rotation is realized with the Arcball-3D technique [3]. Here, the structure is surrounded by an invisible sphere, which can be rotated to rotate the object as well. For the interactive unfolding, we designed a diegetic slider widget, see Fig. 2a. The user can drag the slider handle along the slider axis. The normalized 3D position of the handle is used to interpolate between the folded and unfolded state.

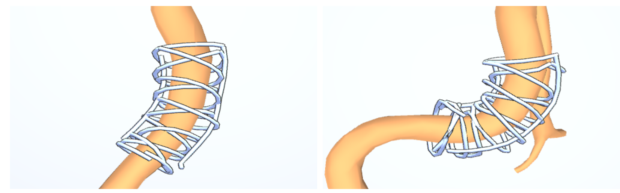


(a) (b)

Figure 3: The illustration shows a bended tubular shape surrounded by a spiral sketch. The distortion during bending is shown for no smoothing (a) and 5-neighborhood Gaussian smoothing (b).

Sketching. The 3D sketches are gathered as sampled 3D points from the input device. To ensure that the sketches are transformed in accordance to the animated unfolding, the points have to be pinned on the CoW. For each sample point, the closest vertex of the structure, its normal and the distance itself are determined. We store these values for each sample point. Thus, a relative description of the sample point position w.r.t. the 3D structure is defined. We use a quaternion to represent the rotation between these two points. During animation, we ensure that the rotation and the distance of the sample points are maintained. Since the pinning of sample points is computationally expensive, the number of them is critical. However, a reduced amount leads to a visual unpleasing representation of the sketch. Therefore, we first equidistantly resample the points and then use 5-neighborhood Gaussian smoothing, see Fig. 3.

Visualization of Sketches. We represent sketches as a 3D structure by creating a tube along the sketched path. This allows the use of shading techniques, i.e., cel-shading with an outlined silhouette. The cel-shading supports shape perception and the silhouette helps the user differentiate between the CoW and sketches, see Fig. 4.



(a) (b)

Figure 4: (a) shows the sketch of a stent in the unfolded state. During the animation to the original folded state the stent adapts to the underlying vessel structure (b).

5 Conclusion

Complex structures, such as patient-individual vessel trees with pathologies, require excellent knowledge of spatial variations and 3D extent. The physician has to mentally combine information from the imaging modalities with the real-life patient data.

In this work, we present an approach to minimize this gap with a semi-immersive 3D presentation of the patient-specific data. The exploration of the 3D scene reflects the patient-individual anatomy of the complex CoW, i.e., the bending of the arteries can be examined and occlusions can be resolved via unfolding. Conventional imaging cannot depict the same information. With the presented work, including the sketches pinned to the unfolding structure, treatment planning can be carried out, see Fig. 4.

In future work, we want to enrich the possibilities for treatment planning with dedicated tools to sketch treatment options such as stents. After that, we want to evaluate our tool with physicians.

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