Segmentation and Visualization of 3D Medical Images through Volume Rendering

1.Davu Mahalaxmi, 2.Dr. K. Sudha Rani

Department of Electronics and Instrumentation, VNR Vignana Jyothi Institute of Engineering and Technology, mahalaxmidavu203@gmail.com

Associate Professor, Department of Electronics and Instrumentation, VNR Vignana Jyothi Institute of Engineering and Technology, sudharani_k@vnrvjiet.in

Abstract: High-dimensional and high-resolution image data is increasingly produced by modern medical imaging equipment. As a consequence, the need for efficient interactive tools for segmentation and visualization of these medical images is also increasing. Existing software include state-of-the-art algorithms, but in most cases the interaction part is limited to 2D, despite the tasks being highly 3D oriented. This project involves interactive medical image visualization and segmentation, where true 3D interaction is obtained with stereo graphics and haptic feedback. Well-known image segmentation algorithms, e.g., fast marching, fuzzy connectedness, deformable models, and live-wire, have been implemented in a framework allowing the user to interact with the algorithms and the volumetric data in an efficient manner. The data is visualized via multi-planar reformatting, surface rendering, and hardware-accelerated volume rendering. We present a case study where liver segmentation is performed in CT images with high accuracy and precision.

Index Terms: *volume haptics, live-wire, deformable simplex mesh, fast marching, volume rendering.*

DOI:10.48047/ecb/2023.12.10.973

1. INTRODUCTION

Today imaging systems provide high quality images valuable in a number of medical applications, e.g., diagnostics, treatment planning, surgical planning, and surgical simulation. The images obtained with modern computed tomography (CT) and magnetic resonance (MR) devices are 3D or sometimes 4D and the resolution is high and steadily increasing. The result is a steady flow of high-dimensional image data to visualize, analyze, and interpret. One of the most important tasks is segmentation, i.e., separation of structures from each other and from the back-ground. Segmentation is needed for, e.g., shape analysis, volume and area measurements, and extraction of 3D models. Lack of contrast between different tissues and shape variability of organs make automatic segmentation hard. By using interactive segmentation [1], expert knowledge is used as additional input to the algorithms and thereby facilitates the task. Interactive segmentation can be divided into recognition and delineation [2]. Recognition is the task of roughly determining object location, while delineation consists of determining the exact extent of the object. Human users outperform computers in most recognition tasks, Corresponding author. while computers often are better at delineation. A successful interactive method combines these abilities to minimize user interaction time, while maintaining user control to guarantee correctness of the result. Examples of softwares for interactive medical image processing and visualization are 3D Slicer [3], MeVisLab [4],and ITK-SNAP [5]. These softwares are designed mainly for use on ordinary workstations, which may become a limitation for complex, highly 3D oriented tasks. An example where it is shown how true 3D interaction can improve segmentation is the Liver Planner [6].

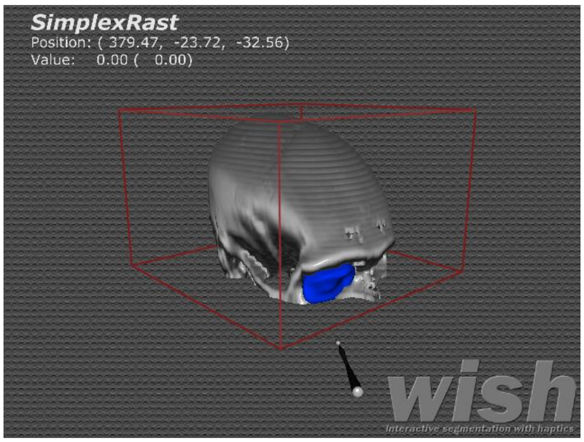


Fig 1 Example Figure

Our approach is to use haptic feedback and stereo graphics in order to obtain true 3D interaction, see Fig. 1. Haptic interaction provides the possibility of simultaneous exploration and manipulation of data by providing controlled force feedback to the user. Direct volume haptics [7, 8] has shown to be useful in volume exploration [9] and for interactive medical segmentation [10]. Our work has involved development and implementation of algorithms for interactive segmentation [11, 12, 13, 14], hardware accelerated volume visualization [15], and volume haptics [16, 17]. These implemementations have been collected in a toolkit called WISH—interactive segmentation with haptics.

2. LITERATURE SURVEY

Interaction in the segmentation of medical images: a survey:

Segmentation of the object of interest is a difficult step in the analysis of digital images. Fully automatic methods sometimes fail, producing incorrect results and requiring the intervention of a human operator. This is often true in medical applications, where image segmentation is particularly difficult due to restrictions imposed by image acquisition, pathology and biological variation. In this paper we present an early review of the largely unknown territory of human-computer interaction in image segmentation. The purpose is to identify patterns in the use of interaction and to develop qualitative criteria to evaluate interactive segmentation methods. We discuss existing interactive methods with respect to the following aspects: the type of information provided by the user, how this information affects the computational part, and the purpose of interaction in the segmentation process. The discussion is based on the potential impact of each strategy on the accuracy, repeatability and interaction efficiency. Among others, these are important aspects to characterise and understand the implications of interaction to the results generated by an interactive segmentation method. This survey is focused on medical imaging, however similar patterns are expected to hold for other applications as well.

User-Steered Image Segmentation Paradigms: Live Wire and Live Lane:

In multidimensional image analysis, there are, and will continue to be, situations wherein automatic image segmentation methods fail, calling for considerable user assistance in the process. The main goals of segmentation research for such situations ought to be (i) to provide effective control to the user on the segmentation process while it is being executed, and (ii) to minimize the total user's time required in the process. With these goals in mind, we present in this paper two paradigms, referred to as live wire and live lane, for practical image segmentation in large applications. For both approaches, we think of the pixel vertices and oriented edges as forming a graph, assign a set of features to each oriented edge to characterize its ``boundariness," and transform feature values to costs. We provide training facilities and automatic optimal feature and transform selection methods so that these assignments can be made with consistent effectiveness in any application. In live wire, the user first selects an initial point on the boundary. For any subsequent point indicated by the cursor, an optimal path from the initial point to the current point is found and displayed in real time. The user thus has a live wire on hand which is moved by moving the cursor. If the cursor goes close to the boundary, the live wire snaps onto the boundary. At this point, if the live wire describes the boundary appropriately, the user deposits the cursor which now becomes the new starting point and the process continues. A few points (live-wire segments) are usually adequate to segment the whole 2D boundary. In live lane, the user selects only the initial point. Subsequent points are selected automatically as the cursor is moved within a lane surrounding the boundary whose width changes as a function of the speed and acceleration of cursor motion. Live-wire segments are generated and displayed in real time between successive points. The users get the feeling that the curve snaps onto the boundary as and while they roughly mark in the vicinity of the boundary. We describe formal evaluation studies to compare the utility of the new methods with that of manual tracing based on speed and repeatability of tracing and on data taken from a large ongoing application. The studies indicate that the new methods are statistically significantly more repeatable and 1.5–2.5 times faster than manual tracing.

User-guided 3D active contour segmentation of anatomical structures: Significantly improved efficiency and reliability:

Active contour segmentation and its robust implementation using level set methods are well-established theoretical approaches that have been studied thoroughly in the image analysis literature. Despite the existence of these powerful segmentation methods, the needs of clinical research continue to be fulfilled, to a large extent, using slice-by-slice manual tracing. To bridge the gap between methodological advances and clinical routine, we developed an open source application called ITK-SNAP, which is intended to make level set segmentation easily accessible to a wide range of users, including those with little or no mathematical expertise. This paper describes the methods and software engineering philosophy behind this new tool and provides the results of validation experiments performed in the context of an ongoing child autism neuroimaging study. The validation establishes SNAP intrarater and interrater reliability and overlap error statistics for the caudate nucleus and finds that SNAP is a highly reliable and efficient alternative to manual tracing. Analogous results for lateral ventricle segmentation are provided.

Liver Surgery Planning Using Virtual Reality:

We have developed LiverPlanner, a virtual liver surgery planning system that uses high-level image analysis algorithms and virtual reality technology to help physicians find the best resection plan for each individual patient. Preliminary user studies of LiverPlanner show that the proposed tools are well accepted by doctors and lead to much shorter planning times.

A constraint-based technique for haptic volume exploration:

We present a haptic rendering technique that uses directional constraints to facilitate enhanced exploration modes for volumetric datasets. The algorithm restricts user motion in certain directions by incrementally moving a proxy point along the axes of a local reference frame. Reaction forces are generated by a spring coupler between the proxy and the data probe, which can be tuned to the capabilities of the haptic interface. Secondary haptic effects including field forces, friction, and texture can be easily incorporated to convey information about additional characteristics of the data. We illustrate the technique with two examples: displaying fiber orientation in heart muscle layers and exploring diffusion tensor fiber tracts in brain white matter tissue. Initial evaluation of the approach indicates that haptic constraints provide an intuitive means or displaying directional information in volume data.

3. METHODOLOGY

Using a Segment surface to hollow a Volume Render:

Volume rendering identifies and classifies relevant information, specifically colors and opacities, and assigns them to voxels based on information about them. Both high quality data and choice of technique affect volume rendering quality.

Volume rendering is a type of data visualization technique which creates a three-dimensional representation of data. CT and MRI data are frequently visualized with volume rendering in addition to other reconstructions and slices. This technique can also be applied to tomosynthesis data.

Volume rendering involves the following steps: the forming of an RGBA volume from the data, reconstruction of a continuous function from this discrete data set, and projecting it onto the 2D viewing plane (the output image) from the desired point of view.

Volume rendering is an important graphics and visualization technique. A volume renderer can be used for displaying not only surfaces of a model but also the intricate detail contained within.

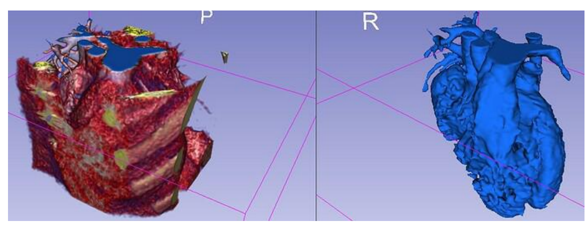
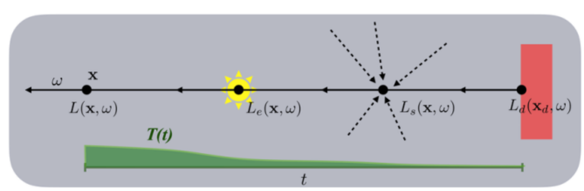


Fig 2 Segment Surface to hollow a Volume Render

The equation for volume render is given below:



Segment multiple vertebrae in spine CT for 3D printing:

Segmentation of the vertebrae refers to the embryonic developmental process that results in the formation of the spine with a series of divided, similar anatomical units, that are the vertebrae.

Vertebrae are the 33 individual bones that interlock with each other to form the spinal column. The vertebrae are numbered and divided into regions: cervical, thoracic, lumbar, sacrum, and coccyx. The 33 vertebrae make up five distinct spine segments. Starting at the neck and going down toward your buttocks (rear end), these segments include: Cervical (neck): The top part of the spine has seven vertebrae (C1 to C7).

The spine is composed of 33 bones, called vertebrae, divided into five sections: the cervical, thoracic, and lumbar spine sections, and the sacrum and coccyx bones. The cervical section of the spine is made up of the top seven vertebrae in the spine, C1 to C7, and is connected to the base of the skull.

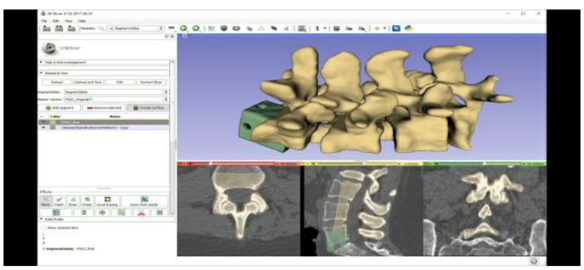


Fig 3 Segment multiple vertebrae in spine CT for 3D printing

Haptic Interaction:

A haptics interface is a system that allows a human to interact with a computer through bodily sensations and movements. Haptics refers to a type of human-computer interaction technology that encompasses tactile feedback or other bodily sensations to perform actions or processes on a computing device.

A haptics interface is primarily implemented and applied in virtual reality environments, where an individual can interact with virtual objects and elements. A haptics interface relies on purpose-built sensors that send an electrical signal to the computer based on different sensory movements or interactions. Each electrical signal is interpreted by the computer to execute a process or action. In turn, the haptic interface also sends a signal to the human organ or body. For example, when playing a racing game using a haptic interface powered data glove, a user can use his or her hand to steer the car. However, when the car hits a wall or another car, the haptics interface will send a signal that will imitate the same feeling on user’s hands in the form of a vibration or rapid movement.

Paradigm / Features	Desktop haptics	Surface haptics	Wearable haptics
Computing platform			
Interface metahorp	Handheld stylus	Bare finger	Whole hand
Controlled avatar	Rigid tool	Virtual finger	Virtual hand
Typical device	 Phantom Premium	 T-Pad	 CyberGrasp

Fig 4 Haptic Interaction

A commonplace haptic technology is mobile phone vibrations during gaming to boost immersion. Haptics leverage force and tactile feedback to enable users and computers to interface with each other. The former simulates certain physical features of the object being virtualized, such as pressure and weight.

4. IMPLEMENTATION

WISH Tool Kit:

The WISH toolkit contains algorithms and methods for interactive medical image analysis with volume visualization and haptics. The toolkit is licensed under the GNU public license (GPL).

The core of WISH is a stand-alone C++ library with implementations of various image analysis algorithms, visualization algorithms, and haptic rendering algorithms. In order to create an interactive application, the library has been integrated with the H3D API 1.5 which is a scene-graph API for visuo-haptic applications. H3D API supports Python scripting, so the user interface for WISH is made with Python's Tkinter package.

The WISH toolkit is the result of a research project in interactive medical image analysis conducted at the Centre for Image Analysis at Uppsala University in Sweden. The toolkit is mainly aimed for PhD students and other researchers in image analysis and related fields that can use the algorithms and ideas for their own research. However, anyone is more than welcome to download WISH to use it, test it, modify it, or improve it.

In order to use the toolkit, it is recommended that you have the following hardware:

- A decent workstation (~3GHz, >1GB)
- A graphics card that supports OpenGL 2.0
- A haptic display from SenseGraphics
- or at least a Phantom haptic device.

and the following software:

- Visual C++ 2005
- H3D API 1.5

The toolkit contains, among other things, implementations of the following:

- Proxy-based volume haptics engine
- Hardware (GPU) accelerated volume rendering
- Fast marching segmentation
- Fuzzy connectedness segmentation
- Deformable model segmentation based on simplex meshes
- Bilateral filtering
- Gradient vector flow (GVF) implemented with PCG and Multigrid numerical schemes
- Comparison of segmentations
- Distance transformations, Gaussian filtering, connected component labeling, and several other "standard" image processing algorithms.
- Voxelization of surface meshes (3D rasterization)

5. EXPERIMENTAL RESULTS

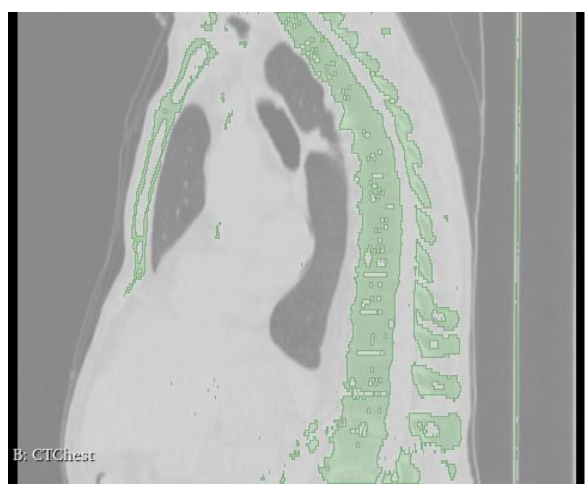


Fig 5 Spine Input

Flow Chart Of CT Spine (Segmentation Tools)

1) THRESHOLD :

RANGE : 120.99 – 1480.28

2) ISLANDS : Keep the selected island

3) SCISSORS : Erase selected path

Selected the erased part from input of CT Chest view in the 3D view.

4) SMOOTHING :

1) Closing (Fill Holes)

Kernel Size : 2.00 mm [3*3*1 pixel]

2) Median

Kernel Size : 4.00 mm [5*5*1 pixel]

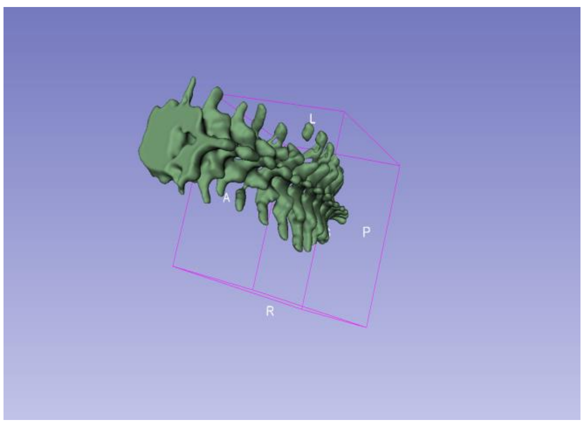


Fig 6 Spine Output

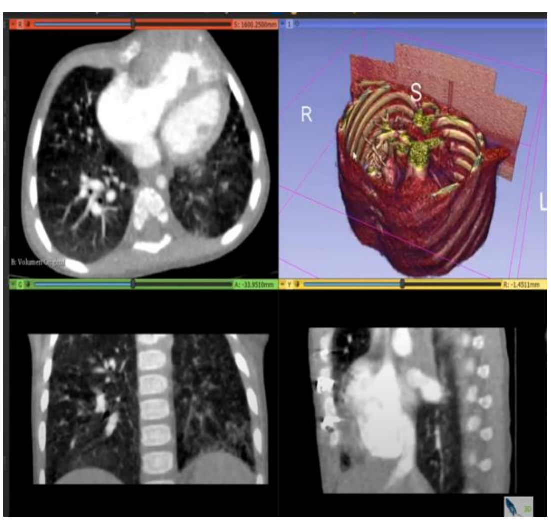


Fig 7 Heart Input

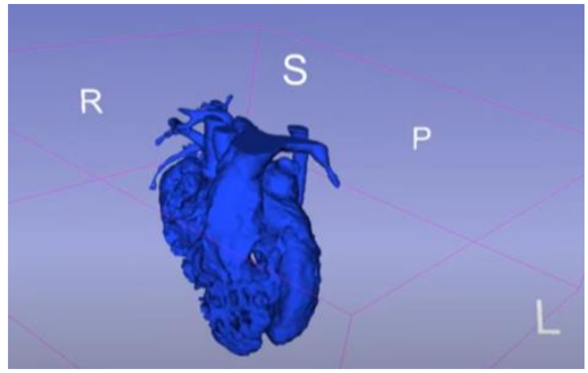


Fig 8 Heart Output

Fig 9 Lungs input

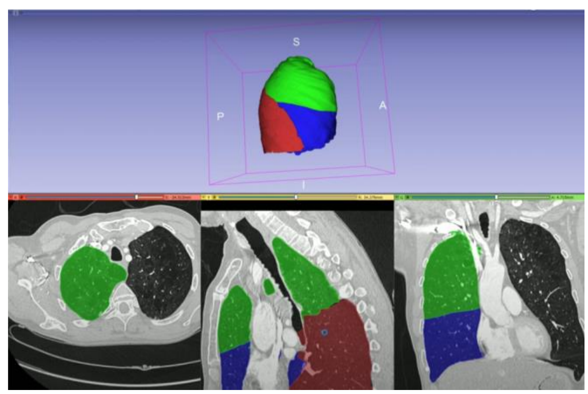


Fig 10 Lungs Output

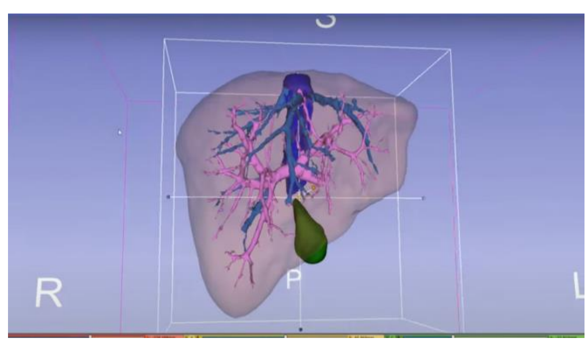


Fig 11 Liver Input

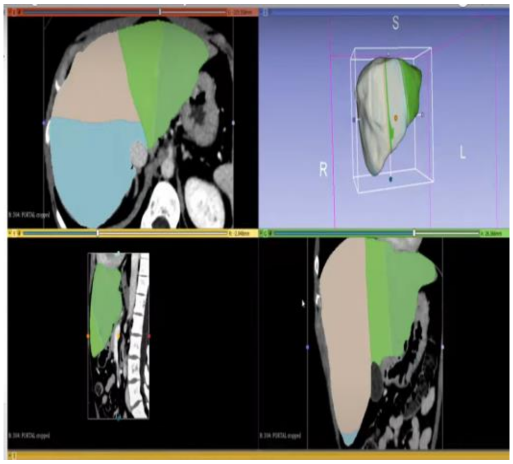


Fig 12 Liver Output

6. CONCLUSION

We have presented our project on interactive medical image segmentation and visualization in a 3D environment with haptic feedback. A number of well-known tools specially tailored and developed for our environment have been integrated into a toolkit. The software is based solely on crossplatform open-source code and is therefore easily extendable. With limited effort, new methods can be integrated by creating wrappers in the form of H3D API nodes. In a case study, we demonstrated the performance of the interactive segmentation tools for liver segmentation from CT data. First, we used fast marching segmentation with interactive seeding in order to obtain a fairly accurate segmentation of the liver with high precision. In the subsequent step, we used our deformable simplex mesh to refine the fast marching segmentation. The results showed a considerable increase of accuracy and high precision. The benefits of using more advanced hardware should be balanced against the increased hardware costs. Although the prices of haptic enabled 3D input devices have decreased significantly lately, they are still more expensive than traditional 2D input devices, which ought to be taken into account in evaluation of our methods. Our bottomline is however that haptic enabled 3D input devices offer many new and exciting possibilities for interactive manipulation and exploration of 3D data.

REFERENCES

[1] S. D. Olabarriaga, A. W. M. Smeulders. Interaction in the segmentation of medical images: A survey. Medical Image Analysis, 5(2):127–142, 2001.

[2] A. X. Falcao, J. K. Udupa, ˜ et al. User-steered image segmentation paradigms: Live wire and Live lane. Graphical Models and Image Processing, 60(4):233–260, 1998.

[3] S. Pieper, M. Halle, R. Kikinis. 3D slicer. In Proc. of IEEE Int. Symp. on Biomedical Imaging, pp. 632–635, 2004.

[4] MeVisLab. http://www.mevislab.de/, 2007.

[5] P. A. Yushkevich, J. Piven, et al. User-guided 3D active contour segmentation of anatomical structures. NeuroImage, 31(3):1116–1128, 2006.

[6] B. Reitinger, A. Bornik, et al. Liver surgery planning using virtual reality. IEEE Comp. Graphics and Applications, 26(6):36–47, 2006.

[7] M. Ikits, J. D. Brederson, et al. A constraint-based technique for haptic volume exploration. In Proc. of IEEE Visualization, pp. 263–269, 2003.

[8] K. Lundin, B. Gudmundsson, A. Ynnerman. General proxybased haptics for volume visualization. In Proc. of World Haptics, pp. 557–560. IEEE, 2005.

[9] K. Lundin, M. Cooper, et al. Enabling design and interactive selection of haptic modes. Virtual Reality, 2006.

[10] M. Harders, G. Szekely. Enhancing human-computer inter- ´ action in medical segmentation. Proc. of Multimodal Human Computer Interfaces, 91(9):1430–1442, 2003.

[11] E. Vidholm, X. Tizon, et al. Haptic guided seeding of MRA images for semi-automatic segmentation. In Proc. of IEEE Int. Symp. on Biomedical Imaging, pp. 278–281, 2004.

[12] E. Vidholm, S. Nilsson, I. Nystrom. Fast and robust semi- ¨ automatic liver segmentation with haptic interaction. In Proc. of MICCAI'06, LNCS 4191, pp. 774–781, 2006.

[13] F. Malmberg, E. Vidholm, I. Nystrom. A 3D live-wire seg- ¨ mentation method for volume images using haptic interaction. In Proc. of DGCI'06, pp. 663–673, 2006.

[14] E. Vidholm, I. Nystrom. Haptic interaction with deformable ¨ models for 3D liver segmentation. In Proc. of MICCAI Workshop, 2007.

[15] E. Vidholm, A. Mehnert, et al. Hardware accelerated visualization of parametrically mapped dynamic breast MRI data. In Proc. of MICCAI Workshop, 2007.

[16] E. Vidholm, J. Agmund. Fast surface rendering for interactive medical image segmentation with haptic feedback. In Proc. of SIGRAD'04, Sweden, 2004.

[17] E. Vidholm, I. Nystrom. A haptic interaction technique for ¨ volume images based on gradient diffusion. In Proc. of World Haptics, pp. 336–341. IEEE, 2005.

[18] C. Zilles, J. Salisbury. A constraint-based god-object method for haptic display. In Proc. of Int. Conf. on Intelligent Robots and Systems, Human Robot Interaction, and Cooperative Robots, pp. 146–151, 1995.

[19] D. C. Ruspini, K. Kolarov, O. Khatib. The haptic display of complex graphical environments. In Proc. of ACM SIGGRAPH'97, pp. 345–352, 1997.

[20] E. Vidholm. Visualization and Haptics for Interactive Medical Image Analysis. PhD thesis, Uppsala University, 2008.