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3D Segmentation and Visualization of Human Brain CT Images for Surgical Training - A VTK Approach*

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Abstract. Simulated surgical planning and training has been proved to be effective in enhancing the performance of surgical operations. 3D medical image modeling and visualization is therefore gaining increasing attention in the research community as the navigation using 3D DICOM data provides a more realistic planning and training environment. However, medical applications often have specific targets, e.g. TB, cancer and tumor. Algorithms developed for the respective applications are designed based on the characteristics, like shape and intensity, of the target. In order to analyze the target for symptom diagnostic or monitoring purposes, the target region needs to be segmented out from its background so that the algorithm output will not be adversely affected by irrelevant signals close to the target. In this paper, we focus on segmentation and visualization, with a use case of developing a 3D environment for Ventricular puncture operation planning and training. The difference between our work and other segmentation techniques is that we need to segment not only one target, but also the path along the surgical tool inserted into the brain. This creates challenges to the algorithm design because a set of segmentation parameters may be effective for one region, but may not be effective for another due to the different data region contrasts, densities, shapes and so on. Segmentation is only an initial step but is necessary in order to conduct the actual surgical training. While many researchers or clinicians waste effort in generating segmentation results, our contribution lies in our VTK approach, which is fast to implement so that the users can focus on the core process. Our experimental results demonstrate the feasibility of providing a realistic 3D visualization and interactive environment for surgical planning and training.

Keywords: Surgical Training · 3D Brain Modeling · VTK · CT Imaging · Hounsfield · Catheter Simulation · Haptic Feedback

1 Introduction

A CT (Computed tomography) scan is an x-ray procedure that creates a stack of cross-sectional images with the help of computer technology. CT images are more detailed than conventional x-ray images and can reveal bones as well as soft tissues and organs. DICOM image slices that CT scans produce are in serial form and present 3D visualization of the human body.

They can reveal abnormal structures and help the physician plan and monitor treatments. 3D visualization plays an important role in diagnostic healthcare, medical research and education. A head CT can be used to evaluate various structures of the brain and look for abnormalities, areas of bleeding, stroke, tumor, etc. The Hounsfield scale is a quantitative measure of radiodensity[11]. Hounsfield Unit (HU) is computed from the values of Rescale Intercept and Rescale Slope available in DICOM images. Pixel values in a CT image are displayed in terms of relative radiodensity. It is displayed according to the mean attenuation of the tissue that it corresponds to on a scale from -1024 to over 3000 on the Hounsfield scale.

HU can be calculated from pixel data as follows[12]:

$$\text{HU} = \text{PixelValue} * \text{RescaleSlope} + \text{RescaleIntercept}$$

Figure 1 [3] shows the general HU values of a human body. In this paper, we present techniques that can segment and visualize different ranges of HU index using the VTK (Visualization Toolkit) library for DICOM images.

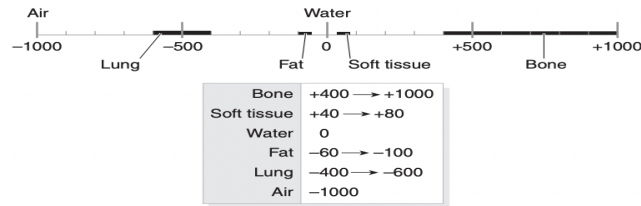


Fig. 1. Hounsfield Units of a Human Body [3]

Segmentation and visualization are two fundamental and necessary steps in medical image analysis. Segmentation aims to separate the different regions in the brain, e.g. bones, white matter, gray matter, tissues and so on, so that the target object, e.g., ventricles or tumor, can be extracted for further detailed analysis. Segmentation provides a navigation map (visualization) for the deployment of surgical tools. In recent years, there is an increasing research effort to develop simulated tools for surgical training and planning. The objective of our work is to provide insight into the feasibility of combining haptic-device feedback with software visualization to simulate surgical operations for clinical training and planning, with the use case of developing a 3D environment for ventricular puncture. Ventricular drainage is commonly performed in neurosurgery departments or in the emergency room. It consists of inserting a catheter into the brain, using a needle, until it reaches the frontal horn to drain cerebrospinal fluid for therapeutic or diagnostic purposes [14]. Figure 2 shows our skull phantom. The long rod is a catheter used by surgeons. They have different sizes of catheter. We used this one because it is quite rigid and thus it does not deform during insertion, whereas smaller catheter are deformable. Once the catheter is in place they can insert through it another tool to drain the ventricle. Nowadays, the learning of this gesture is only performed by companionship: there is no effective simulator for training in this type of surgery. Motivated by this need, we aim to design a haptic-enhanced visual simulator that renders the various layers crossed by the needle during such an operation, so that surgeons get a realistic visual-and-touch feedback when training on this simulator before operating on a patient. The challenge is to model the volume

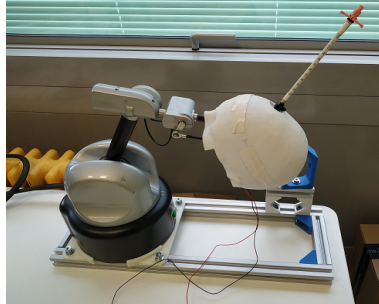


Fig. 2. Left is our haptic-device, and a brain skull phantom with a catheter inserted is displayed on the right.

of the brain, the ventricle, and the virtual needle synchronized with the haptic-device handled by the trainee. The location of the needle tip in the 3D model will activate haptic cues specific to each brain area. The whole trajectory will be recorded for rapid objective evaluation purposes [15]. The 3D model will have to be calibrated with the haptic-device to synchronize the device position with the virtual needle in real-time. In this paper, we focus on the segmentation and visualization steps.

2 Related Work

3D visualization and reconstruction can be achieved using surface rendering and volume rendering techniques. In [1], 3D Visualization of brain MR DICOM images was achieved using these techniques through VTK platform and free plane clipping method was applied to achieve virtual dissection. In 2016, a VTK-based medical image 3D visualization system was built[7] to render the results of 3D reconstruction using two different techniques - the Marching Cubes algorithm and Ray Casting algorithm. A similar 3D rendering software was designed for MR images using vtkFixedPointVolumeRayCastMapper and Microsoft .NET framework[9]. These algorithms have been used widely in medical 3D reconstruction and have proven to be very efficient[2].

Marching Cubes is a high resolution 3D surface reconstruction algorithm. It generates a 3D surface by processing the 3D medical data in scan-line order. The algorithm requires the user to specify a threshold value which is the density value corresponding to the surface that is desired to be visualized.[8] Surfaces corresponding to the threshold are then located and triangles are created. Finally, a visualizable image is constructed by creating normals to the surface at each vertex of the triangle. Ray Casting algorithm is used for rendering 3D models where opacity and color details are collected along the ray traversing path through the entire volume. VTK provides users with functions for both the algorithms mentioned above.

3D visualization plays an important role in detecting abnormalities in human bodies, such as tumors, cancers, blockages, etc. It contributes towards timely detection and treatment. In 2018, the marching cube algorithm was applied to a segmented brain tumor to generate the vertices and the faces to form a 3D model. This information was stored in a stl file [5]. Region-growing algorithms have been used for automatic segmentation of lungs from chest CT scans. Image processing functions from the ITK library and volume rendering methods from the VTK library were also used [10]. In 2018, a brain haemorrhage region detection technique was proposed on DICOM images using the HU-based approach. The segmentation was based on the HU values in the range of 40–50 that

corresponds to the haemorrhages [6]. The above mentioned techniques have been proven to be efficient for segmentation of one target structure, e.g., the lung or abnormalities like a brain tumor, cancer, or haemorrhage. In this paper, we aim at segmenting and visualizing multiple anatomical regions of the human head along the path of a surgical tool. These structures may be the brain, bones, ventricles, and blockages, having very different contrasts and densities. Algorithms designed to target a particular structure characteristics is unlikely to segment effectively other brain regions composed of different material types.

3 Methodology

CT data is used as input and reconstructed in order to prepare for segmentation. 3D DICOM Reconstruction can be implemented using two techniques: surface rendering and volume rendering. In this paper, we present the results of HU-based surface rendering and volume rendering of brain CT DICOM images (Figure 3) using VTK libraries (`vtkContourFilter`, `vtkGPUVolumeRayCastMapper` and `vtkMarchingCubes`).

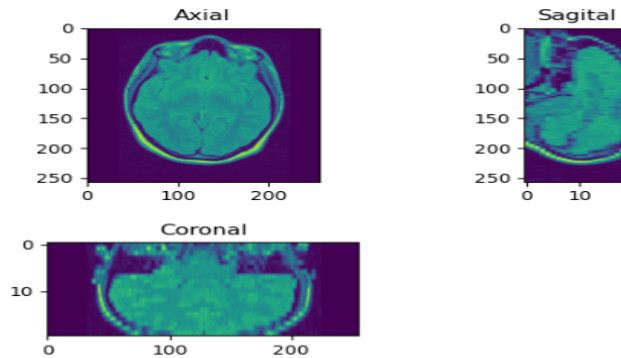


Fig. 3. CT Brain DICOM Images from different views

The challenge of this step is to identify isosurface values, which need to be defined as thresholds in the algorithms in order to visualize the respective surfaces. We first convert raw pixel values to HU values using rescale intercept and rescale slope, that are stored in the DICOM header, and then plot its histogram. As illustrated in Figure 4, there are lots of air, white matter, grey matter, blood, parts of brain and some bones, corresponding to different HU values. Since we know that air exhibits HU value of -1000, we apply thresholding to mask out air from the image. We then move onto surface extraction using the VTK functions mentioned above. Finally, we render the generated 3D surfaces as described below.

3.1 Volume Rendering

Volume rendering can be achieved using `vtkVolumeRayCastMapper`, which maps the volume data from `vtkImageData` using `vtkVolumeRayCastFunction` to calculate the pixels and display them in the render window when signalled by `vtkRenderer`. This mapper uses `vtkTransferFunction` to

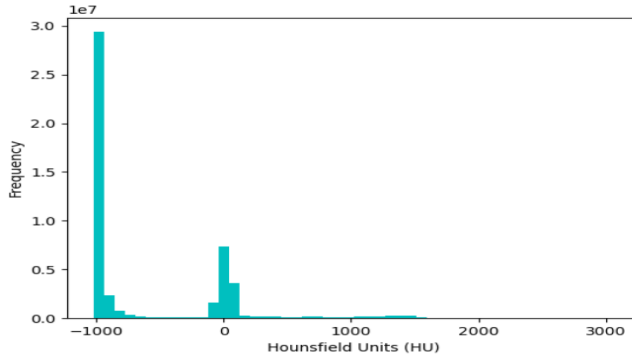


Fig. 4. Histogram of Hounsfield Units

create a 1-D lookup texture that the shader program can use to perform composite ray casting[13]. This transfer function serves as the input to the `vtkVolumeProperty`. The transfer function consists of a piece-wise function called `vtkPiecewiseFunction` for the scalar opacity and a function called `vtkColorTransferFunction` for the color.

3.2 Surface Rendering

Surface rendering can be achieved using `vtkContourFilter`, which creates an isosurface through the data at a specific threshold value (HU value). This function finds points in the volume data where the scalar value corresponds to the threshold value given by the user. It creates isosurfaces by scanning through the data volume and connecting points of the same value. The threshold value provided might occur several times in the data volume. This leads to multiple isocontours being returned by the algorithm.

Marching-cubes is one of the most widely used surface rendering methods. `vtkMarchingCubes` implements marching-cubes technique and is more efficient than `vtkContourFilter` and `vtkVolumeRayCastMapper` methods because surface rendering can be achieved with more resolution and higher precision. `vtkMarchingCubes` is a filter that takes volumetric image data as its input and generates an output of one or more isosurfaces. One or more iso values must be specified to generate the isosurfaces. A min/max scalar range and number of contours can also be specified to generate a series of evenly spaced contour values.

4 Experimental Result

Our 3D Brain CT DICOM images used for visualization were provided by a surgeon at Lyon. Figure 5 shows the properties of these DICOM images. Pixel data is usually given in axial orientation in a high resolution grid of 512x512 pixels.

These images were thresholded to different patches based on the HU values to remove air and generate surfaces for skin, bone and soft tissues. The result of `vtkMarchingCubes` is shown in Figure 6 and Figure 7, where different colours represent different meshes. HU values of +500 to +3000 represent bone in CT images. Figure 8 shows the result of `vtkContourFilter` when a HU threshold

Properties	Value
Slice thickness (mm)	1.25
Pixel Spacing (row, col)(mm)	0.488281,0.488281
Rescale Intercept	-1024
Rescale Slope	1
Number of slices	188
Dimensions	512x512

Fig. 5. Properties of DICOM Images

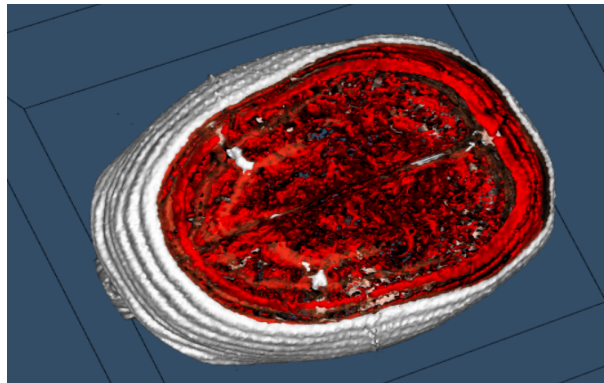


Fig. 6. Surface Rendering of skin, brain and soft tissues with Marching Cubes

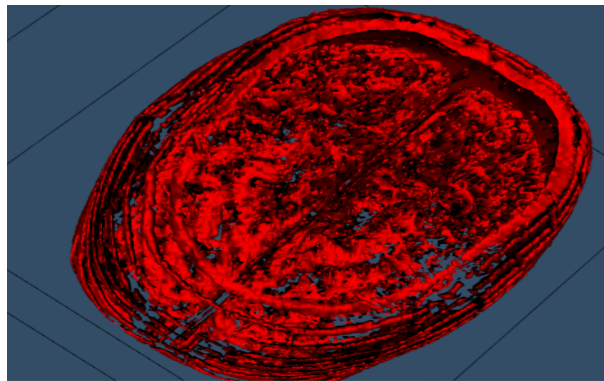


Fig. 7. Surface Rendering of brain and soft tissues with Marching Cubes

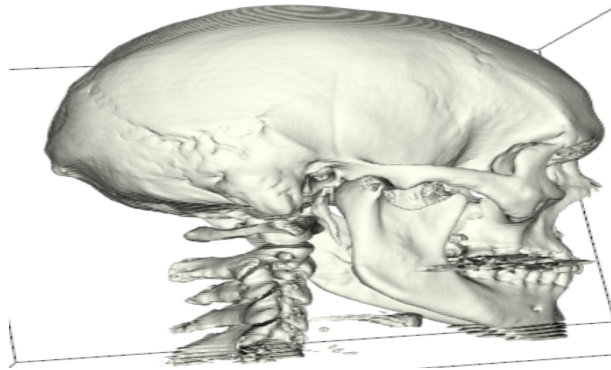


Fig. 8. Surface Rendering of bone structure using vtkContourFilter

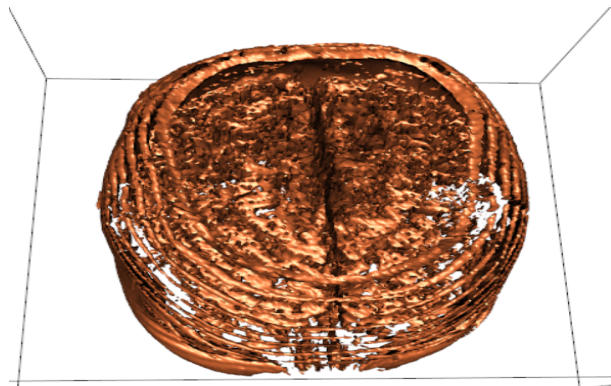


Fig. 9. Surface Rendering of brain and soft tissues with vtkContourFilter

value of 500 was defined in order to extract a surface for bone or bone-like density. Soft tissues and skin were rendered in a similar manner as shown in Figure 9.

The DICOM images were thresholded using a HU value of -1000 to remove all air and then `vtkGPUVolumeRayCastMapper` was used to create a 3D volume of the remaining structures as shown in Figure 10 and Figure 11.

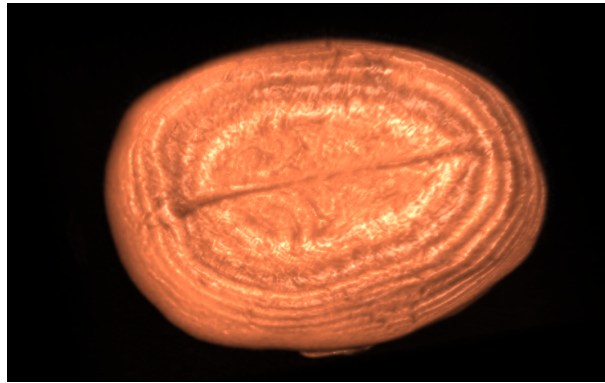


Fig. 10. Result of Volume Rendering using `vtkGPUVolumeRayCastMapper`

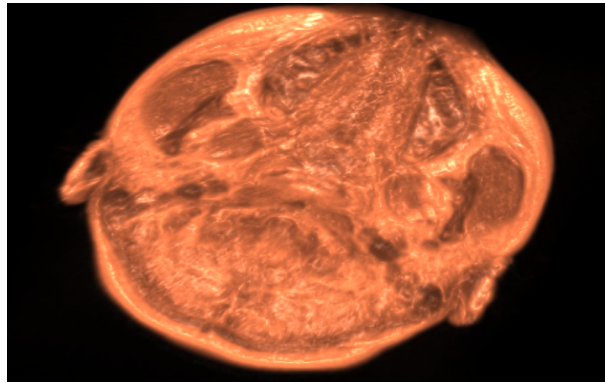


Fig. 11. Result of Volume Rendering using `vtkGPUVolumeRayCastMapper` with more isosurfaces

5 Discussion

Without segmentation, clinicians and surgeons can only rely on visual clues to carry out surgical planning and training. For example, in our use case of ventricular puncture operation, Figure 12 shows how the CT data can be displayed from multiple views along the three major axes to provide

visual guidance to the users. The planned trajectory of the surgical tool (catheter) is projected onto the display. The advantage of 3D segmentation and modeling is to allow the surgical experts to define the relative material values in each segmented region or layer. These material values are mapped onto a feedback force table associated with the haptic-device. Therefore, in addition to the visual guide, users navigating the catheter can also feel a force simulating the pressure generated from the anatomical structures, e.g., bones and soft tissues, when the catheter is inserted into the human brain.

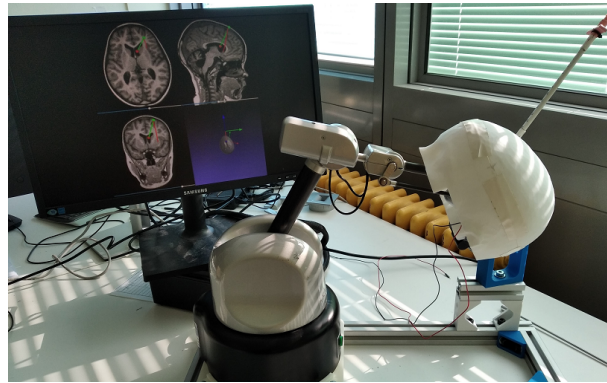


Fig. 12. The screen illustrates visualization of CT data without 3D segmentation and modeling, with our haptic-device and head phantom and catheter inserted.

We observed that it can be challenging when it comes to segment more finely-divided individual structures when these structures have similar HU values or fall under the same HU value window. VTK is not very efficient when it comes to segment structures with small HU ranges. One solution is to apply progressive interpolation between two surfaces so that the gradually changing feedback forces detected can supplement the visualization clue (visual-touch perception) for the clinician or surgeons during the planning /training process. In future work, we will explore this research further.

6 Conclusion

3D reconstruction, modeling and visualization of medical data has been proven to be useful to clinicians and surgeons in identifying abnormalities in the human body and helping them in surgical planning and training, which results in better surgical performance. However, an initial but necessary step is segmentation. While algorithms are often designed for specific targets, e.g., lung and tumor, they are unlikely to be effective on multiple targets, as different regions or layers like bones, arteries and soft tissues have their unique contrasts, material densities and so on, which require specific set of parameter values in the algorithms in order to define the patch boundaries. Different from related work, which focus on a target structure, we aim to segment regions (layers) along the path of a surgical tool inserted into the brain, with ventricular puncture as our use case. In this paper, we presented results of segmentation and visualization of Brain CT DICOM data. Visualization of different surfaces composed of bone, skin and soft tissue was implemented using VTK. Our approach is fast and provides a realistic 3D environment for interactive navigation of

the surgical tool. Our objective is to help the users to focus on the core process of surgical planning and training, without wasting too much efforts on the initial segmentation task.

7 Acknowledgment

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References

1. Du, R., & Lee, H.J. (2019). A Visualization System of Brain MR image based on VTK.
2. Zhao, Kai & Sun, Qiyuan & Liu, Zhenzhong. (2020). 3D Reconstruction of Human Head CT Images Based on VTK. 16-20. 10.1109/ICARM49381.2020.9195291.
3. Lima, R.F., & Marengoni, M. (2015). Visualization 3D Reconstruction - Volume Rendering of Mucus into Paranasal Sinuses. VISAPP.
4. <http://www.intl.elsevierhealth.com/e-books/pdf/940.pdf>
5. Al-Rei, M. (2017). Automated 3D Visualization of Brain Cancer.
6. Phan, Anh-Cang & Văn Quyên, Võ & Phan, Thuong-Cang. (2018). A Hounsfield value-based approach for automatic recognition of brain haemorrhage. *Journal of Information and Telecommunication*. 3. 1-14. 10.1080/24751839.2018.1547951.
7. J. Tan, J. Chen, Y. Wang, L. Li & Y. Bao. (2016) . Design of 3D Visualization System Based on VTK Utilizing Marching Cubes and Ray Casting Algorithm. 8th International Conference on Intelligent Human-Machine Systems and Cybernetics (IHMSC). 192-197. 10.1109/IHMSC.2016.153.
8. William E. Lorensen and Harvey E. Cline. 1987. Marching cubes: A high resolution 3D surface construction algorithm. *SIGGRAPH Comput. Graph.* 21, 4 (July 1987), 163-169. DOI:<https://doi.org/10.1145/37402.37422>
9. Madusanka, N., Zaben, NA, Shidaifat, AA, & Choi, H.-K. (2015). 3D Rendering of Magnetic Resonance Images using Visualization Toolkit and Microsoft.NET Framework. *Journal of Multimedia Information System* , 2 (2), 207-214. <https://doi.org/10.9717/JMIS.2015.2.2.207>
10. Medeiros, Raul & Barata Rodrigues, Murillo & Filho, Pedro Pedrosa. (2017). Segmentation and Visualization of the Lungs in Three Dimensions Using 3D Region Growing and Visualization Toolkit in CT Examinations of the Chest. 10.1109/CBMS.2017.23.
11. Hounsfield scale. (2018, March 14). Retrieved March 21, 2018, from https://en.wikipedia.org/wiki/Hounsfield_scale
12. Surface Extraction: Creating a mesh from pixel-data using Python and VTK. (2014, October 26). Retrieved March 5, 2022, from <https://pyscience.wordpress.com/2014/09/11/surface-extraction-creating-amesh-from-pixel-data-using-python-and-vtk/>
13. Real-time volume rendering with hardware-accelerated raycasting. (2006, April 18). Retrieved March 13, 2022, from <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.121.304&rep=rep1&type=pdf>
14. Toma AK, Camp S, Watkins LD, Grieve J, Kitchen ND. External ventricular drain insertion accuracy: is there a need for change in practice? *Neurosurgery* 2009;65(6):1197-200. 10.1227/01.NEU.0000356973.39913.0B
15. Raabe, C., Fichtner, J., Beck, J., Gralla, J., & Raabe, A. (2018). Revisiting the rules for freehand ventriculostomy: a virtual reality analysis, *Journal of Neurosurgery JNS*, 128(4), 1250-1257. Retrieved Dec 9, 2020, from <https://thejns.org/view/journals/j-neurosurg/128/4/article-p1250.xml>