Concurrent Visualization of and Mapping between 2D and 3D Medical Images for Disease Pattern Analysis

Mei Xiao[1], Jung Soh[1], Thao Do[1], Oscar Meruvia-Pastor[1] and Christoph W. Sensen[1]

[1]Department of Biochemistry and Molecular Biology, Faculty of Medicine,
University of Calgary

Abstract. Brain lesions caused by several neurologic disorders have a range of shapes, sizes and locations. Discovering the patterns of lesion development in patients will assist in evaluating the damages and monitoring the recovery of brain tissues. We have developed a software tool to highlight and display regions of interest in 2D medical images and their 3D mesh model counterparts. This tool can help researchers visualize and compare the brain lesions and tissues in multiple dimensions and various user-controlled configurations.

Keywords: 3D image data, 3D mesh, connected component, consistent mesh, virtual reality, brain lesion

1   Introduction

Injuries, autoimmune diseases (e.g. multiple sclerosis [1]), and brain tissue infections can damage brain tissues and create lesions. Such brain lesions may have different sizes, shapes and locations. Some lesions are benign, but others could be fatal. The causes for brain lesions vary to a great extent. Therefore, it is difficult to fully understand how different kinds of lesions develop, how they affect our cognitive abilities and how effective different treatments are.

CT and MRI imaging techniques are frequently used to trace the sizes, shapes and locations of lesions [2]. Slices from CT or MRI image stacks can show the exact details of the lesions [3]. However, measuring the lesion size, shape and location is a challenging task [4]. Although well-trained doctors and radiology specialists can read through the 2D slices to reconstruct 3D shapes of the lesions mentally and assess the anatomical locations of the lesions without the help of software tools, this is not easy for most researchers. More importantly, as large scale studies are implemented in order to monitor lesion changes and identify disease developmental patterns, tools for the automated comparison of various brain tissues over time are required [5]. To accomplish those tasks efficiently, it is important to be able to rapidly build 3D graphical models, which allow users to intuitively find and study the lesion patterns of interest in both 2D image stacks and 3D models.

To efficiently manage and correlate lesions in both 2D image stacks and 3D models, we have developed a software package to allow users to load/unload 2D

image stacks and 3D models, pick a lesion in a 2D image stack (3D models) and find the corresponding 3D model (2D images) in real time.

2 Methods

To illustrate the use of our software tool, we use T1, T2 and T2 FLAIR MRI images of multiple sclerosis (MS) patients as an example. Our software tool is generic. It can work with any 3D scan for which a stack of TIFF or JPEG images exists. For our example, patients were recruited in Halifax, Nova Scotia, Canada.

Figure 1 shows a slice of a T2 FLAIR MRI scan of a patient. The circled areas show the MS lesions caused by inflammation, which appear as noticeably bright areas. All the scans of the same patient were registered together to make comparisons across scan sessions meaningful. MS lesions were manually segmented from the T2 FLAIR images, and T2 images were also consulted for confirming lesions identified on FLAIR.
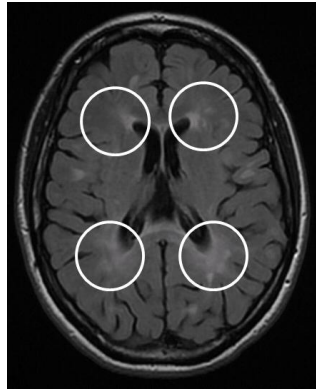

Fig. 1. A slice from an MRI scan of a multiple sclerosis (MS) patient. The circled areas contain lesions, appearing as the bright areas.

2.1 2D Image Stacks and 3D Models

Multiple 2D image stacks can be loaded to the display panel (see Figure 2). The manually segmented lesion mask stack is overlaid onto the FLAIR image stack to give users an anatomical reference. Users can move the slider to navigate through 2D image stacks.

3D models of the lesions are built from the manually segmented 2D lesion masks. We have developed a program to quickly extract surface models of the lesions. This program preserves connectivity of voxels such that connected components of a model can be easily selected and separated. Multiple 3D models can be loaded to the 3D display panel (see Figure 2). A 2D lesion image stack is visually linked to its corresponding 3D model by using the same color and transparency properties.
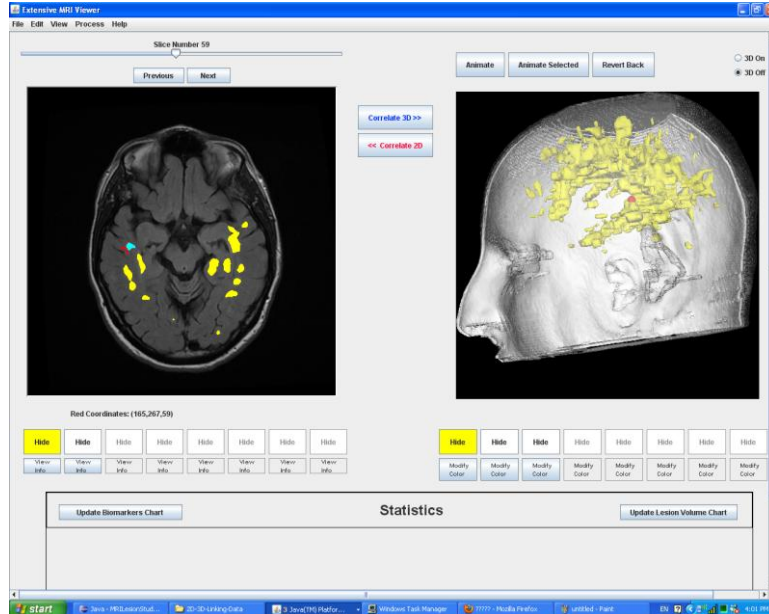
Fig. 2. Concurrent visualization of 2D and 3D images. A stack of FLAIR images and segmented lesion masks (left) and the 3D models of the head and the lesions (right) are linked by using the same color.

2.2   2D-3D Mapping

Our surface model extraction algorithm uses the voxel coordinates from the image stacks to create vertices for the 3D models. Therefore, a voxel in a 2D image stack can be mapped to a point on a 3D model, and vice versa, establishing two-way 2D-3D mapping. Our visualization tool has three display panels. Figure 3 shows the data flow of the program. Users can load multiple 2D image stacks and multiple 3D models into the panels. When the user double clicks on the 2D image stack, the (x, y) coordinates of the selected point and the slice number z are recorded, and a sphere centered on the corresponding (x, y, z) position is shown on the 3D model. Likewise, when the user double clicks on the 3D model, the (x, y, z) coordinates of the selected point on the 3D model are recorded, and the 2D image slice corresponding to the z-position is displayed with a red crosshair at coordinates (x, y) to indicate the corresponding 2D location of the selection. Using these mapping features, the user can freely explore 2D-3D correspondence of voxels in either direction.

We also use *vtkPolyDataConnectivityFilter* from the Visualization Toolkit (VTK) to retrieve the connected components [6, 7]. As a result, when a surface point on the 3D model has been selected, an isolated lesion containing that point can be displayed in a new panel. Furthermore, the 2D corresponding portions of this isolated lesion are recursively detected from the 2D image stack and highlighted [8] (see Figure 4).
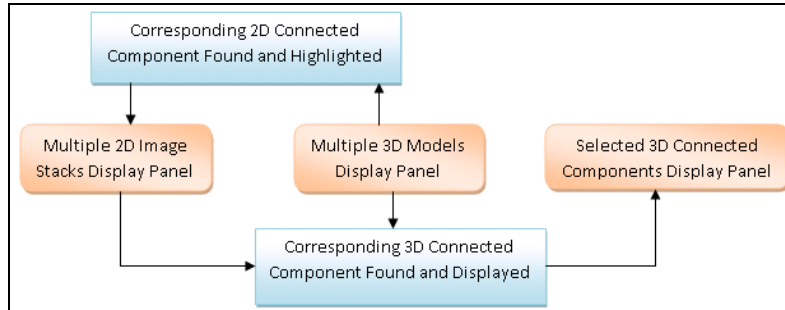
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Fig. 3. Flow of control for displaying 2D-3D correlations.

3   Results and Discussion

We have developed a medical image processing and visualization software package by using the Java programming language and VTK visualization toolkit. Our package can be used to visualize and compare brain lesions in both 2D images and 3D mesh models. Multiple 2D image stacks and 3D models provide a clear anatomical reference. Selecting and highlighting of an individual lesion from the whole model provides a good mechanism for users to study and compare lesions of their interest in large scale and in real time.

The key to the successful isolation of a connected lesion from the whole model is the connectivity of the 3D mesh model. In order to do this, we need a 3D model that not only accurately represents the shape of the lesions from the original MRI, but is at the same time consistent in a way such that the vertices of an isolated lesion belong to one connected component. Extended marching cubes algorithms can be used to create mesh with connectivity and topology maintained [9]. However, those algorithms are applied to the whole image stack and every voxel will be checked, making them very time consuming. Therefore, we have developed a program that uses the flood filling algorithm to quickly build 3D models to achieve a closed and consistent mesh.

To find disease developmental patterns, accurate models play an important role. Although there are many automatic image segmentation programs that have been developed for handling MRI images [10], MS lesions usually have fuzzy boundaries (see Figure 1), and therefore still need to be manually segmented by neuroscience experts.

In addition to the natural connectivity of lesions in the MRI images, tools are also available to allow users to cut a whole model into multiple pieces to enhance anatomical comparisons and pattern analysis. For example, Xiao et al (2010) provided a generic model building algorithm. By using a virtual dissection method, various models can be built quickly and efficiently. Together with our current model visualization tool, a highly flexible selection-based 2D/3D model comparison tool can be developed for studying and discovering disease patterns. We plan to integrate the two packages to obtain a seamless model construction and lesion analysis tool in the future.
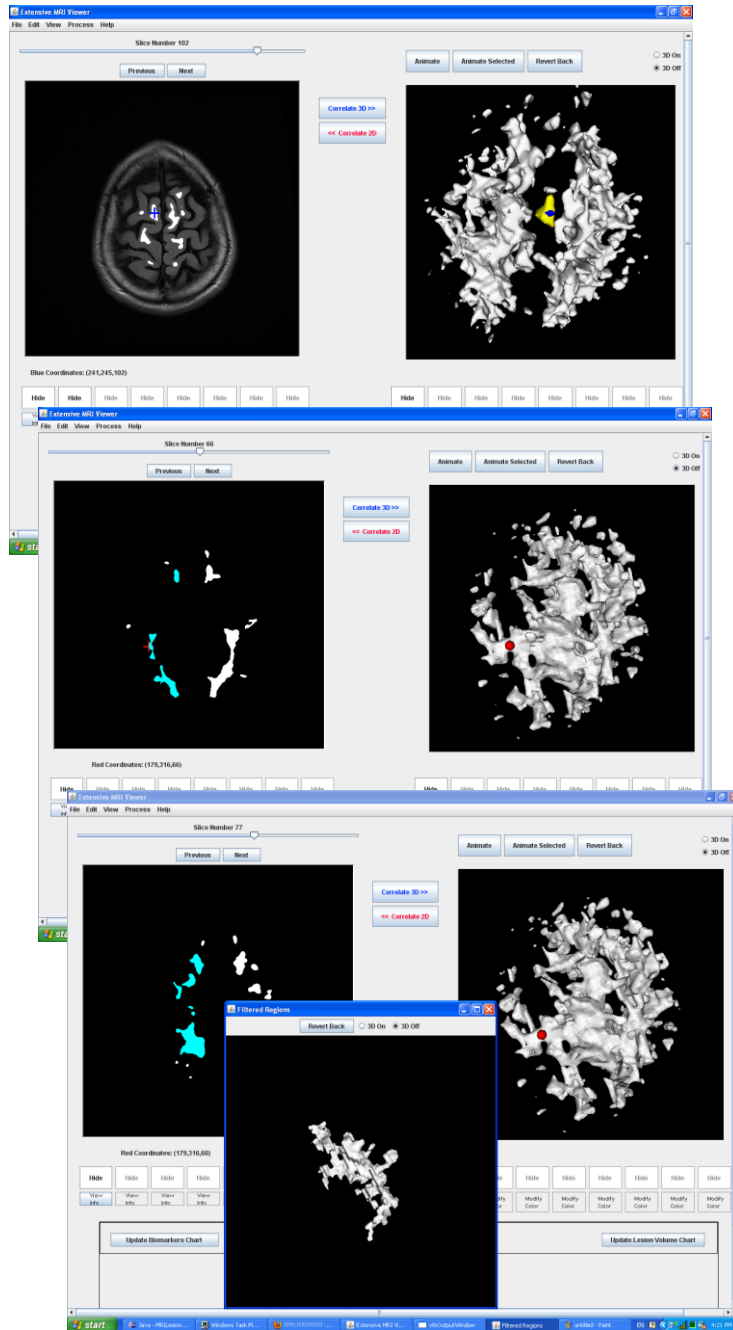
Fig. 4. 2D-3D mapping. A 2D point on a slice of a stack (blue crosshair) is mapped to a nearest surface point (blue sphere) on the 3D model (top). A 3D point (red sphere) is mapped to the corresponding lesion (highlighted in cyan) and the exact matched 2D point (red crosshair) in the 2D image stack (middle). The selected 3D lesion is displayed in a new panel (bottom).

4 Conclusion

Brain lesions resulting from damages by diseases such as MS, stroke, shock wave brain trauma have been the subjects of intensive studies. However, large scale and intensive studies need to be done in order to fully understand the progression of those diseases and find effective treatments. Our software tool is a complementary package which can assist researchers in the visualization of brain images in multiple dimensions and the resulting models. Our future work will focus on adding more features to display shape analysis results and quantifying changes in lesions over a time span. Work is underway to make the software available from a public repository.

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