SATURN2: An Improved Software Tool for Neuroimaging Analysis

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Abstract

In this paper we present a new version of Saturn (Software Application of Tensor Utilities for Research in Neuroimaging) software tool. This is a package created for DTI (Diffusion Tensor Imaging) analysis and visualization, specially in the areas of tensor computing, fiber tractography and DTI quantitative analysis. Saturn2 has been designed and developed for its use in diagnostic and research environments by the Laboratorio de Procesado de Imagen of the University of Valladolid. The program has been written in C++, based on the Open Source Libraries ITK (Image Toolkit), VTK (Visualization Toolkit) and Qt.

Saturn2 is available online for Windows, Linux and Mac at http://www.lpi.tel.uva.es/saturn/

1 Introduction

DTI (Diffusion Tensor Imaging) is a very attractive modality of MRI (Magnetic Resonance Imaging) as it can be used to study the structural features of the neural tissues and the connections between brain regions. This technique measures the rate and the main direction of diffusion of the water molecules inside the biological tissues; the water contained in the brain cells tends to diffuse more easily along axons, so the main direction of diffusion within a voxel can be used to estimate the structures of the nervous fibers.

This method employs six or more different diffusion weighted images to estimate the tensorial field used to represent the diffusion of each voxel. The process of following the neural tracts that exist through the brain is called tractography. Physicians can use DT imaging as a diagnostic and evaluation method. Multiple studies have demonstrated the capacity of DTI for the diagnosis of several neurologic diseases like sclerosis, epilepsy[1] or cancer[2].

There are many software tools for DTI processing and visualization like DTIStudio [3], 3DSlicer [4] or MedINRIA [5], to cite some of them. Most of them are focused on specific applications like tractography or volume visualization, while others offer a lot of image processing and visualization processing options.

With Saturn2, we have developed a free open source software tool for DTI analysis and visualization. Saturn2 can be used for tensorial estimation from DW (Diffusion Weighted) Image volumes, extraction of statistical maps, tractography generation of fiber tracks to explore and understand the connectivity of the white matter structures within the brain, and so forth. It can be used in research studies to study the importance of white matter tissues in development and the pathologies of the brain.

This new version features, among others, a more robust and stable framework, a modular and easily extensible architecture, a simple and user friendly graphic user interface, a new batch mode for working with large data sets and new modules like hyperline tractography and glyph visualization. Previous versions of Saturn have been presented in other papers like [6] and [7]. In this paper we focus on the new features developed for this version.

The paper is structured as follows: Section 2 describes the architecture of the program and the interface redesign. Section 3 explains the new modules added to this new version. In section 4 a comparison with similar applications is presented, and finally the conclusions and future lines are outlined in Section 5.

2 Main architecture of Saturn2

This new version of Saturn has been designed and built using open source, multiplatform libraries. For 3D visualization employs VTK (Visualization Toolkit), which contains a great set of classes for data representation and manipulation. ITK (Image Toolkit) has been used for implementing the image processing algorithms and the Qt framework library for the graphic user interface objects. All these libraries are written in C++ and can be compiled in multiple platforms.

The goals that we have tried to implement with Saturn2 can be summarized as follows:

• Open source code.
• Multiplatform design.
• Easy to use interface.
• Robust implementation.
• Modular architecture.
• Complete documentation.
2.1 Redesigned general structure

A major effort has been made in the design of the architecture of this new version. The classes which form the program’s main structure can be seen in the fig.1, based on the model-view architecture paradigm. The main classes are:

- **SaturnBase**: Defines and declares the basic objects of the program (image types, filters, viewers, loaders classes, etc.).
- **SaturnGUI**: Contains the Graphic User Interface objects, panels and dialog windows.
- **SaturnMain**: Defines the main framework of the program and its connection with the GUI panels.
- **PipelineManager**: Acts as manager between any type of data (volumes of images, tensorial data, tridimensional actors, etc.) and the user items.
- **ViewerFramework**: Creates and controls the viewer windows and the user interactions with them.
- **ControlData**: Implements the control of the algorithms; executes the pipeline between the input and the output and allows the addition of plugin panels. All the features of the program (tractography estimation, image segmentation, etc.) are split into modules that are controlled by this class.

![Diagram of Saturn2 main classes.](image)

The algorithms created for image processing and visualization are included in separate classes, also included as library modules written in C++ and they can be compiled and linked with the main interface independently. The separation of the control data classes into easy to use modules facilitates the addition of new functionalities by developers.

2.2 Interface redesign

One of the main goals of this new version is to simplify the usability of the program in order to be used by inexperienced users. A general view of the interface can be seen in figs. 2 and 3. It is divided in three main parts: the Data Management panel, the Options panel and the Visualization Area.

1. **Visualization Area.** It is composed by three 2D viewers (capable of representing different orthogonal cuts of a volume or different volumes and is used to define the ROI (Region of Interest) maps) and one 3D viewer (able to show the different 3D actors of the scene: isosurfaces, fiber tracts, glyphs, multiplanar reconstruction, etc.).

2. **Data Management panel.** Placed on the upper left area of the main window, displays a list of the loaded data. There are four data types managed by Saturn2: DWI data (on DICOM or Nrrd file format), DTI or tensor data (on vtk or Nrrd file format), scalar data (as vtk, JPEG, PNG, TIFF or raw data) and 3d model data (as vtk files). All these data types can be visualized, processed, renamed and removed from the workspace panel with a simple pop up menu.

3. **Options panel.** Placed on the lower left area of the main window, provides the user with an easy way to manipulate the parameters and options of the different DTI processing features. In order to facilitate the usability for inexperienced users, a great number of processes have been redesigned, simplified or automatized, making the use of the program much more streamlined for the final user. For example, with Saturn2, once the tensor data is loaded, a tractography of the brain can be created with just two clicks: the user has to define the ROI (by drawing it on the viewer) and push a button; if there is no ROI selected, an automatic tractography registration method guided by a dialog window creates the ROIs and tractographies without the user’s intervention. Other DTI tools, like 3DSlicer [4] requires a much higher number of actions to perform.

3 New modules in Saturn2

In addition to the new structure, three new modules have been added to Saturn2 for data visualization as well as analysis and an easy to use batch processing mode.

3.1 Glyph visualization

One of the most useful methods for visualize detailed information of a tensor field in a small area are glyphs visualization. A glyph is an icon or a geometrical figure which represents the data at the location of each diffusion tensor. Many of the multiple properties contained in the diffusion tensor of a point can be represented by the aspect of the glyph.
For this new version, we have developed a new glyph module for visualizing tensor fields. A screenshot of this module can be seen in Fig. 2. Simple geometric figures can be used to represent the glyph actors, like cones, boxes, arrows, spheres and superquadratic ellipsoids. The parameters that can be used to transmit information are:

- **Shape**: The shape can be modified according to the eigenvectors and the eigenvalues, making easier to differentiate glyphs by its anisotropy degree.
- **Size**: One of the most useful data indicators. Glyphs can be scaled according to its eigenvalues or a combination of the mode and the fractional anisotropy indexes. This method highlights the most lineal tensors over the rest, keeping the proportions of the glyph.
- **Orientation**: Determined by the eigenvectors of the glyph.
- **Color**: Several anisotropy indexes can be used to colorize the data: Fractional anisotropy, Relative Anisotropy, Geometrical Coefficients $C_l$, $C_p$, $C_s$ or the Orientation of the main eigenvector.
- **Filtering by anisotropy index**: Only the glyphs within a selected range of the selected anisotropy index are shown.

To provide the maximum possible interaction with glyphs there are four implemented methods to define the ROI. The first one is directly drawing the ROI over the 2D viewers where we want to show glyphs. Another way is defining a Volume of Interest for the data. Also it can be done interactively translating and resizing a widget around the 3D viewer. Finally, the points defined by a fiber tract previously created can be used to display the glyphs. After created, the glyphs can be saved as a 3D vtk model.

### 3.2 Hyperlines visualization

As a complement of fiber tractography, an hyperline visualization module has been added to Saturn2. An hyperline is a tube like structure with a elliptical cross section used to display fiber tracks and the tensorial data contained. In this implementation, the semiaxis of the ellipsoidal section varies according to the main eigenvalue, and the proportion between the main and the secondary eigenvalue. The main axis follows the orientation of the main eigenvector.

Hyperlines are a useful way to visualize the properties of the tensorial data at each voxel. A screenshot of this module can be seen in Fig. 3.

### 3.3 Batch processing mode

To facilitate the work with great number of files, we have implemented a batch processing mode. A custom script can be easily created by the user, able to use all the modules of Saturn2 (automatic DTI tractography, DTI quantitative analysis, automatic registration, etc.). Two scripts can be combined forming a loop, so a complicate serie of steps can be elementary replied for a large list of data sets. This a very useful feature in clinical research, where the quantitative analysis of a great number of image volumes is needed.

![Figure 2. SATURN 2 featuring glyph visualization.](image)

![Figure 3. SATURN 2 featuring hyperlines visualization.](image)
Features | DTIStudio | 3D Slicer | MedINRIA | CAMINO | BioIMAGE | SATURN
---|---|---|---|---|---|---
Platform | Win, Mac, Linux | Win, Mac, Linux | Win, Mac, Linux | Win, Mac, Linux | Win, Mac, Linux | Win, Mac, Linux
Open Source | No | Yes | No (part) | Yes | Yes | Yes
FileTypes | DCM, vtlk, Raw, Phillips GE | DCM, vtlk, Raw, Analyze, Nrrd | Analyze, vtlk, DCM, Gpl, Metatlfile, Nrrd | Yes | NoTI, Raw, Analyze, DCM, Nrrd | Metatlfile, Nrrd
Batch mode | No | Yes | No | Yes | Yes | Yes
DTI, Mask estimation | Yes | Yes | Yes | Yes | Yes | Yes
Filter DWI | Yes | Yes | Yes | Yes | Yes | Yes
2D, 3D Vis. | Yes | Yes | Yes | Yes | Yes | Yes
Tractography | Yes | Yes | Yes | Yes | Yes | Yes
ROI edition | Yes | Yes | Yes | No | Yes | Yes
Create ScalarMaps | Yes | Yes | Yes | Yes | Yes | Yes
Image Filters | No | Yes | No | Yes | Yes | Yes
Segmentation | No | Yes | No | No | Yes | Yes
Registration | Yes | Yes | Yes | Yes | Yes | Yes
ROI, Fiber Stats | Yes | Yes | Yes | Yes | Yes | Yes

References


5 Conclusions and future lines

Saturn2 is a powerful and valuable application which contains visualization and processing capabilities for DTI data, comparable with other tools currently used by the scientific community. It features a robust and extensible architecture, an easy to use interface and new visualization and processing modules.

We have also put special care on the multiplatform compatibility. Saturn2 has been compiled, tested and used in Windows, Mac and Linux (RedHat and Ubuntu). Other small improvements of this version are: active color bars, 3D outlines of data actors, simple snapshot buttons, new interaction widgets and more intuitive interactor methods.

Saturn2 is currently being used by physicians and neurologists in their research work. For future developments, we are planning to create simple versions for facilitate its use by physicians and untrained users as a diagnostic tool. Other planned modules are an Animation Module and a plugin for integration of pre-computed XML and C++ stand-alone programs outside the source code.

Saturn2 can be freely downloaded at [10].

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