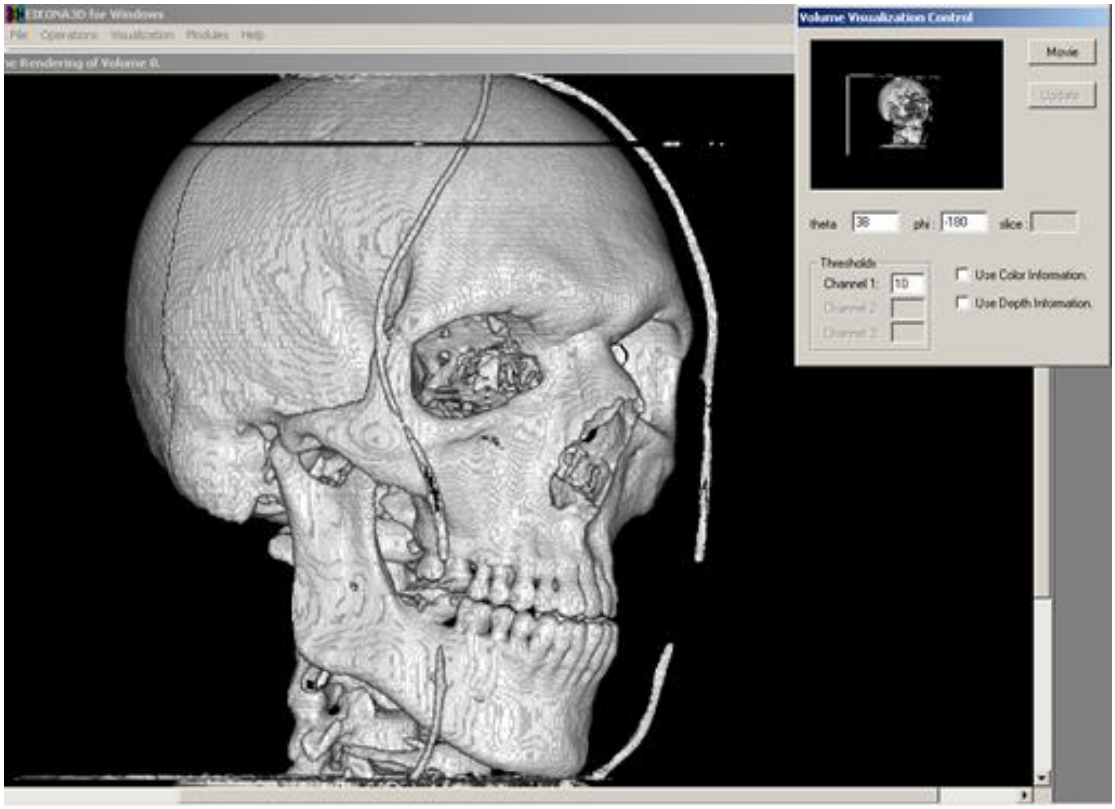
EIKONA3D

A software package for 3D Image Processing, Analysis and Visualization.

Version 3.2.3.1

Part I: Introduction and User's Guide



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EIKONA3D Manual
PART I: Introduction and User's guide

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1. Introduction

EIKONA3D for Windows is an integrated, powerful and flexible software package for 3D image processing, analysis and visualization. It is based on an extensive library of routines related with the suitable manipulation of the specifically designed data structures and the multitude of the supported 3D processing, analysis and visualization algorithms. EIKONA3D provides a suitable friendly and easy-to-use Graphical User Interface (GUI) that gives easy access to all 3D image processing operations through a suitable menu structure. In addition, it guides the user to the selection of the suitable input/output parameters for each routine through carefully designed dialog boxes and it displays suitable error/result notification messages. EIKONA3D GUI was developed for the Microsoft Windows environment and, thus, it has the look and feel of a usual Windows program.

EIKONA3D has a modular format. New EIKONA3D modules can be easily built and incorporated in the executable. Furthermore EIKONA3D Library can be used as a stand-alone Application Program Interface (API) for the development of custom 3D processing applications for both Windows and UNIX platforms using the C programming language.

The present document discusses the hardware requirements of EIKONA3D package, guide you step by step to the installation process, explains the utilized 3D data representation, provides an overview of the features of the 3D image processing operations.

2. User's Guide

2.1 3D Data Representation

Three-dimensional data (volume) handling is achieved effectively via the use of a data structure that keeps all the necessary information for the volume, which is the following:

data type: The supported data types for a single volume element (voxel) are `unsigned char`, `int`, and `float`. The first can also be used for storing binary data.

color type: This specifies whether one or three channels should be used. One channel is used for binary or grayscale volumes and three channels for color volumes (e.g. RGB, CMY, HSI, HSV, HLS).

dimensions: The dimensions of the three-dimensional array that stores the volume data. Supposing that the 3D data represent a number of two-dimensional frames, the dimensions are the number of frames and the number of rows and columns of each frame.

VOI position: The user can specify a VOI (Volume Of Interest), that is a subpart of the volume, in order to process only that part.

pointer to 3D data: The pointer(s) to the three-dimensional array(s) in memory. In the case of use in a Windows application program, additional pointer to data handles are provided.

user field: An additional string field is provided, which can be used by the user to store volume-related information, such as name, description, etc.

This data structure enables the uniform manipulation of all the supported 3D data combinations, that is binary/8-bit/integer/floating-point data in one/three channels. All library routines can be applied either on the entire volume or on a user-specified VOI.

2.2 EIKONA3D Library features

The library routines can be divided in several categories. A brief description for each category is given below:

Memory Allocation/Deallocation routines: These include routines for allocating and deallocating memory space for keeping 3D data and related data structures that are to be processed. In addition, there are routines for initializing a volume structure and for performing volume integrity tests.

Input/Output routines: These include routines for reading and writing 3D data (volumetric images) to disk. Routines are provided for reading and writing 3D data as a sequence of 2D frames in RAW, TIFF, Targa, BMP, JPEG, GIF, PBM, PGM and PPM formats, or as one file in raw format. In the first case, each frame is stored in a different file (in the case of raw format separate files are created for each channel), so

that it can also be opened as a 2D image, whereas the filenames are composed of a base-name, sequential numbering and an extension. In the case of raw format a different extension is required for each channel. In the second case, all frames are stored in one file in a frame-row-column (*z*-*y*-*x*) sequence. An additional routine is provided for dumping data in ASCII format, so that they can be previewed by any ASCII editor.

Basic Operation routines: These include routines for performing several basic operations on volume data. These operations include clearing of a VOI with a user-specified value, copying a VOI of a volume to a selected position in another volume, extracting a frame of a volume to a 2D image, loading a 2D image in a volume frame, converting volumes between the different data types and performing arithmetic operations between volumes, such as logical AND, OR, XOR operations.

Filtering routines: These include routines for performing 3D linear and non-linear filtering operations on a volume. There are routines for histogram calculation, histogram equalization, moving-average filtering, median filtering (standard median, running median, multistage median and weighted median are supported), min/max filtering, filtering with user-specified 3D *L*-filters, adaptive filtering, and generalized filtering with user-specified 3D FIR filters via convolution or FFT. Finally, there are routines for volume interpolation and decimation.

Edge Detection routines: These include routines for 3D edge (surface) detection. Several techniques for edge detection are supported, including a 3D extension of Sobel masks, a 3D Kirsch edge templates, a 3D Laplace operator, a 3D range operator and edge detection through 3D Hough Transform.

Region Segmentation routines: These include routines for 3D region segmentation. Several segmentation techniques are supported, which include thresholding, region growing, region splitting, region merging and region split-merging. Also, region labeling and object counting are supported.

Measurement routines: These include routines for 3D measurements. Surface and volume measurements are supported, as well as calculation of the bounding box in a volume and finding of the minimum and maximum voxel values.

Transform routines: These include routines for performing several transforms on the volume data. The supported transforms are the FFT (Fast Fourier Transform) and the Inverse FFT, the DCT (Discrete Cosine Transform) and the Inverse DCT. In addition, there are routines for performing convolution, for calculating the auto-correlation of a volume, for calculating the correlation between two volumes, for 3D power spectrum estimation using an extension of the Blackman-Tukey method, for transforming a complex volume between real/imaginary and magnitude/phase representations and, finally, for transforming a 3D power spectrum to 3D image for visualization.

Morphology routines: These include routines for performing 3D morphological operations on binary objects represented by binary volumes. There are routines for performing the basic morphological operations, that is Minkowski addition and Minkowski subtraction, dilation, erosion, opening and closing, using any user-defined structuring elements. In addition, there are more complex routines for performing three-dimensional morphological shape decomposition using one structuring element or a set of structuring elements.

Rearrangement routines: These include routines for rearranging the data of a volume. There are routines for rotating a volume around its center by +/-90 degrees around any axis or, generally, around any selected point by any specified angles. Furthermore, there are routines for mirroring the volume data around its center or around specific axes or planes.

Resizing routines: These include routines for resizing a volume in different ways. There are routines for uniform zooming and decimation (with the same integer factor for all dimensions), for 3D interpolation/decimation (Nearest Neighbor or trilinear) with any factor for each dimension, for linear frame interpolation/decimation, and for shape-based binary frame interpolation. Finally, there is a routine for adding zero frames between the existing ones, which can be useful for visualizing 3D contour data.

Visualization routines: A simple volume visualization provided by EIKONA3D is the display of the volume frames as video frames that can be displayed in a backward/forward mode. Furthermore there is a routine for producing a frame gallery image for a simultaneous preview of all volume frames. Routines are provided for sectioning a volume with a plane of any orientation and visualizing the section, and for visualizing a volume using parallel projection (normal, average, or maximum projections are supported) under any user-specified angles. Finally, there are routines for producing a 3D surface representation of a volume for surface rendering and routines for volume rendering (with the options of using depth and/or color information).

2.3 EIKONA3D GUI Descrption

The various operations of EIKONA3D package are organized into the hierarchical menu structure of a friendly graphical user interface. A front view of the EIKONA3D GUI can be seen in Figure 1.

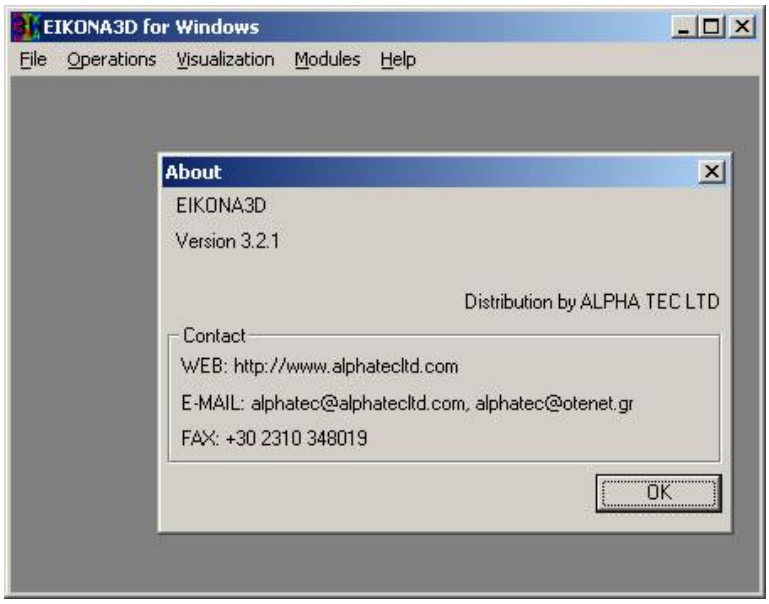

Figure 1: A front view of EIKONA3D displaying the *About* dialog box.

For the majority of operations, the same procedure is followed: the user selects an operation from the menu, gives the input and/or output volume and specifies all other possible required parameters. Before proceeding to the description of each operation,

we shall describe the handling of the two most common dialog boxes, which are the *Select Input Volume* dialog box and the *Select Output Volume* dialog box:

Select Input Volume dialog box**:** It prompts the user to select a volume as input to a selected operation. *Volumes* are referred to by a number 0,1,… while the user can use the *Information* field to keep some notes for the selected volume. Almost all operations can be applied to a subpart of the volume referred to as VOI (Volume Of Interest), which can be specified by enabling the tag *Change VOI* and giving the desired values in the fields *Low VOI* (minimum frame index), *Up VOI* (maximum frame index), *Top VOI* (minimum frame row index), *Bottom VOI* (maximum frame row index), *Left VOI* (minimum frame column index), *Right VOI* (maximum frame column index). The volume dimensions are also displayed in this dialog box.

Select Output Volume dialog box**:** It prompts the user to select a volume as output to a selected operation. An existing volume or, in most cases, a new one can be selected. If an existing volume is currently selected, its data type, color type, dimensions and information field are displayed, whereas, if a new (not already in use) volume is selected, the indicated data type, color type and dimensions are displayed. Here, the user can also change the information field of the finally selected volume. If the finally selected volume (after clicking the OK button) is an existing one and any of its data type, color type, or dimensions are not appropriate for the selected operation, the user is prompted to confirm its destruction and appropriate reallocation or to cancel the current operation.

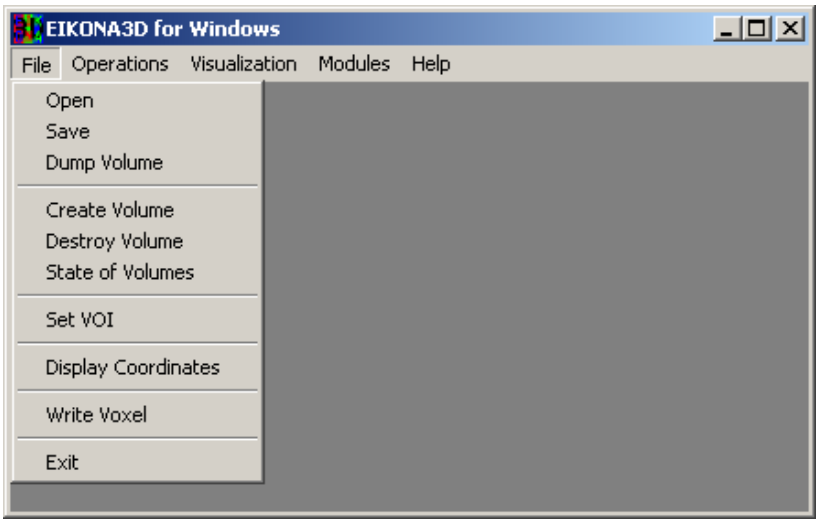

Figure 2: A view of the File menu.

The main window of EIKONA3D has a menu bar consisting of the following drop-down menus: **File**, **Operations**, **Visualization**, **Modules** and **Help**. The menu options of each menu are described in the following subsections.

4.3.1 File menu

This menu includes file I/O operations and some other basic volume operations, which are described below. A view of this menu can be seen in Figure 2.

Open: This menu item enables the user to load a volume from disk into memory. It first displays the *Open* dialog box, where the user should specify all necessary information, depending on the format with which the volume is saved on the disk. The user specifies the path in the *Look in* field and the file format in the *Files of type* field. The other options depend on the file format. Finally, he selects the volume where the frames from disk are to be loaded into in the *Select Volume to Open* dialog box.

For all the supported formats except Raw Volume, the volume data is saved in a series of files (image sequence) of the form [base][index].[extension], each one related to a simple frame (see below for more details on each format). The filename base and extension is common for all the files of an image sequence, whereas the frame index is unique for each frame. In addition, the indices should be consecutive. Thus, in the *Open* dialog a series of files should be specified for opening. EIKONA3D provides a useful feature to help in this way; when the user selects a random file belonging to the image sequence that has to be opened, the necessary information (filename base, lower frame index, upper frame index, frame index length) is automatically determined, provided the image sequence follows the naming conventions of EIKONA3D. The user can still modify the automatically determined fields (e.g. in the case only a subset of an image sequence need to be opened). The *Frame Index Length* field determines the index format; zero value means that there are no leading zeros in the index (e.g. [base0.ext, base1.ext, …, base10.ext, …, base100.ext, …]), whereas a non-zero value specifies a fixed length index (e.g. a value 2 should be specified for the frame sequence [base00.ext, base01.ext, …, base99.ext]). Below, the special characteristics of each supported format are discussed:

- *Raw Image Sequence*: It means that the volume is saved as a sequence of frames in raw format having filenames of the form [base][index].[extension]. For each frame, each channel is supposed to be saved in a different file with the same filename base

and index but with different extension. The user should give the necessary information to specify the frame filenames (filename base, lower frame index, upper frame index, frame index length, an extension for each channel), the data type (`unsigned char` [UC], `int` [I], or `float` [F]), the color type (1 channel [1 Channel] or 3 channels [3 Channels]) and the dimensions (width, height) of each frame in the corresponding fields. An example of opening a raw image sequence is shown in Figure 3.

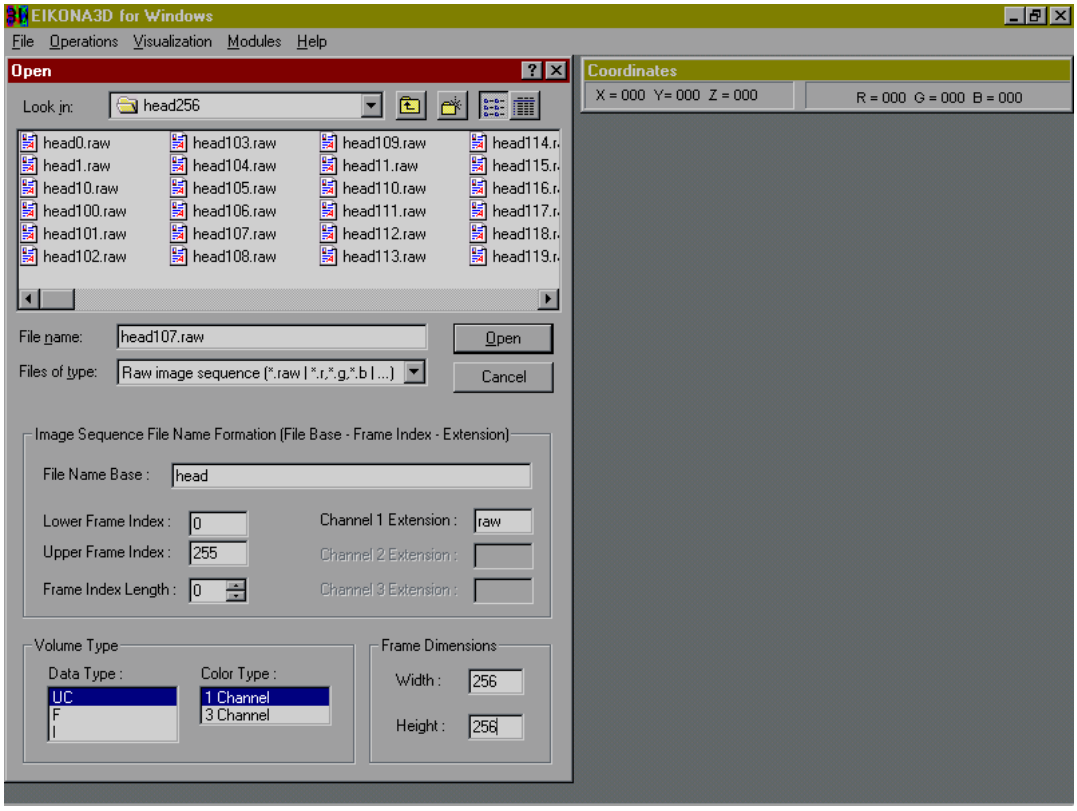

Figure 3: An example of opening an image sequence in `.raw` format.

♦ *Raw Volume*: It means that the volume is saved as one file in raw format. The data sequence is supposed to be channels-frames-rows-columns. The user should specify the filename, the data type, the color type, the lower and upper frame to be loaded from the file, and the dimensions of each frame (width, height).

♦ *TIFF Image Sequence*: It means that the volume is saved as a sequence of frames in TIFF format having names of the form [base][index].[extension]. In this case, there is one file per frame, independently of the color type, and one extension for all frames (`.tif` by default). The data type is `unsigned char`, whereas the color type (1 or 3 channels) and the frame dimensions are derived from the TIFF files. The user should give the necessary information to specify the frame filenames

(filename base, lower frame index, upper frame index, frame index length, extension) in the corresponding fields.

- *BMP Image Sequence*: It means that the volume is saved as a sequence of frames in BMP format (`.bmp` extension by default). The same as for TIFF image sequence hold.
- *Targa Image Sequence*: It means that the volume is saved as a sequence of frames in Targa format (`.tga` extension by default). The same as for TIFF image sequence hold.
- *GIF Image Sequence*: It means that the volume is saved as a sequence of frames in GIF format (`.gif` extension by default). The same as for TIFF image sequence hold.
- *JPEG Image Sequence*: It means that the volume is saved as a sequence of frames in JPEG format (`.jpg` extension by default). The same as for TIFF image sequence hold.
- *PBM Image Sequence*: It means that the volume is saved as a sequence of frames in PBM format (`.pbm` extension by default). The same as for TIFF image sequence hold.
- *PGM Image Sequence*: It means that the volume is saved as a sequence of frames in PGM format (`.pgm` extension by default). The same as for TIFF image sequence hold.
- *PPM Image Sequence*: It means that the volume is saved as a sequence of frames in PPM format (`.ppm` extension by default). The same as for TIFF image sequence hold.

Save: This menu item enables the user to write a volume from memory to disk. The user first selects the volume to be saved in the *Select Volume to Save* dialog box. Then, the *Open* dialog box is displayed, where the user should specify all necessary information depending on the format with which the volume is to be saved on the disk. The user specifies the path in the *Save in* field and the file format in the *Save as type* field. The other options depend on the file format. EIKONA3D provides the following alternatives for the file format:

- *Raw Image Sequence*: It saves a volume of any data type and color type on disk as a sequence of frames in raw format having names of the form

[base][index].[extension]. The user should specify the frame filenames (filename base, lower frame index, frame index length, an extension for each channel).

- *Raw Volume*: It saves a volume of any data type and color type in one file on the disk in a channels-frames-rows-columns sequence. The user should specify only the volume filename.
- *TIFF Image Sequence*: It saves a volume of `unsigned char` data type and any color type on disk as a sequence of frames in TIFF format having names of the form [base][index].[extension]. The user should specify the frame filenames (filename base, lower frame index, frame index length, extension). The user should further specify the TIFF format options in the *TIFF Options* dialog. The options are the compression type (no compression, LZW, Pack Bits) and the photometric image type (Min White/Min Black for grayscale volumes, RGB for color volumes).
- *Targa Image Sequence*: It saves a volume of `unsigned char` data type and any color type on disk as a sequence of frames in Targa format having names of the form [base][index].[extension]. The user should specify the frame filenames (filename base, lower frame index, frame index length, extension). For a color volume, the user should further specify the image resolution (16/24/32 bits/pixel) in the *Targa Option* dialog.
- *JPEG Image Sequence*: It saves a volume of `unsigned char` data type and any color type on disk as a sequence of frames in JPEG format having names of the form [base][index].[extension]. The user should specify the frame filenames (filename base, lower frame index, frame index length, extension). The user should further specify the JPEG format options in the *JPEG Options* dialog. The options are the image quality factor (0...100) and, for color volumes, the output image type (grayscale, color) and the usage of color subsampling.
- *PBM Image Sequence*: It saves a volume of `unsigned char` data type and one channel color type on disk as a sequence of frames in PBM (Portable Bit Map) format having names of the form [base][index].[extension]. The user should specify the frame filenames (filename base, lower frame index, frame index length, extension). This format is intended for binary volumes (containing only black and white voxels). The user should further select between Raw and ASCII image type in the *PBM/PGM/PPM Option* dialog.

- *PGM Image Sequence*: It saves a volume of `unsigned char` data type and one channel color type on disk as a sequence of frames in PGM (Portable Gray Map) format having names of the form [base][index].[extension]. The user should specify the frame filenames (filename base, lower frame index, frame index length, extension). This format is intended for grayscale volumes. The user should further select between Raw and ASCII image type in the *PBM/PGM/PPM Option* dialog.
- *PPM Image Sequence*: It saves a volume of `unsigned char` data type and any color type on disk as a sequence of frames in PPM (Portable Pixel Map) format having names of the form [base][index].[extension]. The user should specify the frame filenames (filename base, lower frame index, frame index length, extension). This format is intended for color volumes but can also be used for a grayscale volume. The user should further select between Raw and ASCII image type in the *PBM/PGM/PPM Option* dialog.

Dump Volume: It writes the contents of a volume to a specified file in ASCII format. The user first selects the volume through the *Select Input Volume* dialog box and then specifies the name of the ASCII file through the *Dump Volume* dialog box.

Create Volume: It creates a new volume with the data type, color type and dimensions specified by the user in the displayed *Select Volume to Create* dialog box.

Destroy Volume: It frees the memory occupied by a specific volume, specified by the user in the displayed *Select Volume to Free* dialog box. The user can select and destroy more than one volumes, using the *Destroy* button, before he closes the dialog with the *Close* button.

State of Volumes: In the *State of Volumes* dialog box the user can see the current state (dimensions, color type, data type and information field) of any of the volumes that are in use.

Set VOI: In the *Set VOI* dialog box the user can set the VOI of a volume, in the same way as in the *Select Input Volume* dialog box.

Display Coordinates: This is a toggle (on/off) option. When it is on, and the cursor is within a display window, the cursor co-ordinates are displayed at the upper right corner of the main window. For grayscale volumes the grayscale value of the current voxel is also displayed, while for color volumes, the RGB values are displayed. By clicking with the right mouse button inside the COORDINATES window, the user can select between the RGB, XYZ, Lab and HLS color spaces for color value representation.

Write Voxel: This menu item enables the user to place a white voxel value at the first voxel pointed by the cursor after the selection. This operation can be used to put "seeds" in volumes, which can be useful for some region segmentation operations.

Exit: It destroys all volumes and exits EIKONA3D program.

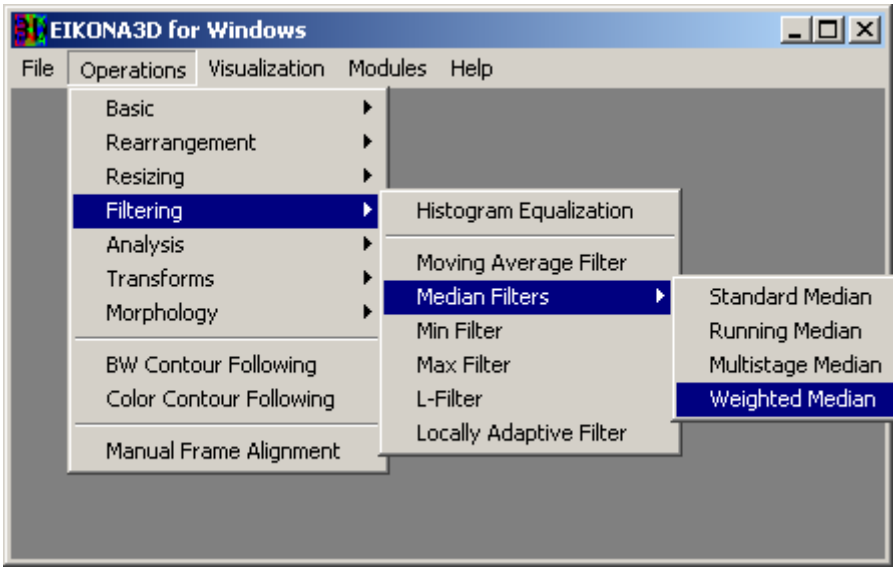

Figure 4: A view of the Operations menu.

4.3.2 Operations menu

This menu leads to the various routines of the EIKONA3D library for the 3D processing of volumes. In most cases, the functions require an input volume and an output volume, selected through the *Select Input Volume* and *Select Output Volume* dialog boxes, and possibly some related parameters, given through additional dialog boxes. Processing is performed only within the volume of interest (VOI) that can be uniquely specified for each input volume. The volumes that are presented in the corresponding list, during the selection of input volume, are only those related to the

certain function to be performed, in order to prevent the user from selecting a non appropriate volume. In addition, this menu includes the operation of manual contour following, which is extremely useful in certain applications e.g. in 3D microscopy. A view of this menu can be seen in Figure 4. The menu items are described in detail below.

Basic: This sub-menu includes a number of basic operations that can be performed on volume data, which are described below.

- **Clear Volume:** It clears a VOI of a volume with a specified value. The user first selects the volume and VOI through the *Select Volume to Clear* dialog box and then the desired value through the *Clear Volume* dialog box.
- **Copy Volume:** It copies a VOI of a volume to a specified position in another volume. The user first selects the input volume and VOI through the *Select Input Volume to Copy* dialog box and the output volume through the *Select Output Volume for Copy* dialog box. If an existing volume is selected as output, then he is prompted to give the destination position in the output volume through the *Give Offsets for Copy* dialog box.
- **Logical AND:** It performs the bit-wise AND logical operator between two volumes (for binary volumes). The user first selects the two input volumes through two successive *Select Input Volume* dialog boxes and then the output volume through the *Select Output Volume* dialog box.
- **Logical OR:** It performs the bit-wise OR logical operator between two volumes (for binary volumes). The same procedure as in **Logical AND** is followed.
- **Logical XOR:** It performs the bit-wise XOR logical operator between two volumes (for binary volumes). The same procedure as in **Logical AND** is followed.
- **UC to F conversion:** It converts a volume with `unsigned char` data type to a volume with `float` data type. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box.
- **F to UC conversion (with scaling):** It converts a volume with `float` data type to a volume with `unsigned char` data type using scaling (the input value range is scaled to the range 0…255). The user selects the input volume through the *Select*

Input Volume dialog box and the output volume through the *Select Output Volume* dialog box.

- **F to UC conversion (with truncation):** It converts a volume with `float` data type to a volume with `unsigned char` data type using truncation (input values less than 0.0 are set to 0 at output, whereas input values greater than 255.0 are set to 255 at output). The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box.

Rearrangement: This sub-menu includes operations that rearrange the data of a volume, which are the following:

- **Symmetric:** It produces the symmetric of a volume in respect to the center. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box.

Resizing: This sub-menu includes a number of operations that change the size of a volume:

- **Uniform Zooming:** It enlarges a volume with the same specified zooming factor for all three dimensions. The user selects the input volume through the *Select Input Volume* dialog box, gives the zooming factor through the *Give Zooming factor* dialog box and selects the output volume through the *Select Output Volume* dialog box.
- **Uniform Decimation:** It decimates a volume with the same specified decimation factor for all three dimensions. The user selects the input volume through the *Select Input Volume* dialog box, gives the decimation factor through the *Give Decimation factor* dialog box and selects the output volume through the *Select Output Volume* dialog box.
- **3D Interpolation/Decimation:** It transforms a volume using any specified interpolation/decimation factor for each dimensions. The user first selects the input volume through the *Select Input Volume* dialog box. Then, he selects the interpolation options through the *3D Interpolation Options* dialog box. Here, the user can give the factors for the three dimensions or specify that the factors are to be derived from the output volume dimensions. Also, he can select between Nearest Neighbor and linear interpolation (the first is faster, whereas the second gives better

results and is recommended). Finally, the user selects the output volume through the *Select Output Volume* dialog box.

- **Frame Interpolation/Decimation:** It transforms a volume using any specified interpolation/decimation factor for only the *z* dimension, that is it changes the number of frames. The user first selects the input volume through the *Select Input Volume* dialog box. Then, he selects the interpolation options through the *Frame Interpolation Options* dialog box. Here, the user can give the factor for the *z* dimension or specify that the factor is to be derived from the output volume dimensions. Only the linear interpolation option is available since Nearest Neighbor simply reproduces or cuts frames. Finally, the user selects the output volume through the *Select Output Volume* dialog box.
- **Binary Frame Interpolation:** It doubles or triples the number of frames of a binary volume using a shape-based interpolation method. The user first selects the input volume through the *Select Input Volume* dialog box. Then, he selects the interpolation options through the *Binary Frame Interpolation Options* dialog box. Here, the user can specify whether edge coherence (edge thickening, useful for frames containing contours) is to be used and select between the two available interpolation factors. Finally, the user selects the output volume through the *Select Output Volume* dialog box.
- **Zero Frame Padding:** It increases the number of frames of a volume by inserting zero-valued frames between the existing ones. This can be useful for visualizing special kinds of volumes, like those containing frames with contours. The user selects the input volume through the *Select Input Volume* dialog box, gives the padding factor through the *Give Zero Padding Factor* dialog box and, finally, selects the output volume through the *Select Output Volume* dialog box.

Filtering: This sub-menu includes several 3D filtering operations, which are the following:

- **Histogram Equalization:** It performs histogram equalization of a volume. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box.
- **Moving Average Filter:** It performs filtering of a volume using the moving average filter. The user selects the input volume through the *Select Input Volume*

dialog box and the output volume through the *Select Output Volume* dialog box and also gives the dimensions of the 3D window mask through the *Give Window Dimensions* dialog box.

- **Median Filters:** It performs filtering of a volume using the 3D median filter. This sub-menu provides four different implementations of the median filter, which are the following:
  - **Standard Median:** The standard 3D median filter. The same procedure as in **Moving Average Filter** is followed.
  - **Running Median:** It performs filtering of a volume using a faster implementation (running) of the median filter. The same procedure as in **Moving Average Filter** is followed.
  - **Multistage Median:** It performs filtering of a volume using the multistage implementation of the median filter. The same procedure as in **Moving Average Filter** is followed, with the difference that only one parameter is given for the 3D window size, as it can only be cubic.
  - **Weighted Median:** It performs filtering of a volume using the weighted median implementation of the median filter. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box and, finally, specifies the source of the weights, which can be either the file `WIN_UC3D.PAR` or an existing volume. In the first case, the weights are loaded in an unused volume, indicated to the user, and can be reused later. In the second case, the user selects the weights volume through the *Select Weights Volume* dialog box.
- **Min Filter:** It performs filtering of a volume using the minimum filter. The same procedure as in **Moving Average Filter** is followed.
- **Max Filter:** It performs filtering of a volume using the maximum filter. The same procedure as in **Moving Average Filter** is followed.
- **Locally Adaptive Filter:** It performs locally adaptive filtering of a volume, that is filtering dependent on the local region content. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box.

Analysis: This sub-menu includes other sub-menus which, are the following:

- **Histogram:** It enables the calculation of the histogram of a volume, selected through the *Select Input Volume* dialog box, with the following two options:
  - **Histogram (pdf):** It calculates and displays the pdf of the histogram.
  - **Histogram (cdf):** It calculates and displays the cdf of the histogram.
- **Edge Detection:** It performs edge detection on a volume with the following options:
  - **Range:** It performs edge detection using the range operator. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box and also gives the dimensions of the 3D window mask through the *Give Window Dimensions* dialog box.
  - **Compass:** It performs edge detection using the 3D Kirsch masks. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box and also specifies the direction of the detected edge planes through the *Plane direction (0,45,90,135)* dialog box.
  - **Sobel:** It performs edge detection using the 3D Sobel masks. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box.
  - **Laplace:** It performs edge detection using the Laplace operator. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box.
  - **Hough:** It performs edge detection using the Hough Transform. The user selects the input volume (it should be a binary one) through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box and also gives the dimensions of the parameter space (integer volume) and the threshold value for the parameter space through the *Give Int. Volume Dimensions and Threshold* dialog box.
- **Region Segmentation:** It performs region segmentation on a volume with the following options:
  - **Threshold:** It performs region segmentation using simple thresholding. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box and also gives the threshold value through the *Give threshold value* dialog box.

- ◊ **Region Grow:** It performs region segmentation using the region growing technique. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box, gives the threshold value for region specification through the *Give threshold value* dialog box and, finally, is prompted to give the seeds with the mouse.
- ◊ **Region Merge:** It performs region segmentation using the region merging technique. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box and also gives the threshold value for region specification and the maximum desirable number of regions through the *Give Threshold and Max No Regions* dialog box.
- ◊ **Region Split:** It performs region segmentation using the region splitting technique. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box and also gives the threshold value for region specification through the *Give threshold value* dialog box.
- ◊ **Region Split-Merge:** It performs region segmentation using the region split-merge technique. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box and also gives the threshold value through the *Give threshold value* dialog box.
- ◊ **Label/Count objects:** It performs region (a region is considered as an object) counting and labeling. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box. The user is notified for the number of objects found. The output of the labeling is a grayscale volume containing the labels 1,2,3,… for each connected region found (0 is the background).
- ◊ **View Labelled Volume:** It enables the user to visualize a labeled volume by assigning the desired colour to each object (region) and hiding/unhiding any object. The user selects the input labeled volume through the *Select Input Labeled Volume* dialog box and the output volume through the *Select Output Volume* dialog box. Then, the *Labeled Volume View* dialog appears and the user can set the RGB values for each identified object through the corresponding sliders or

edit boxes, or hide/unhide any object through the *Display Object* toggle. Any visualization method can be used in parallel to visualize the output volume, where any changes are updated through the *Update All* and *Update Current* buttons. The procedure is terminated by the user through the *Close* button.

- **Metrics:** It performs several measurements on a volume, which are the following:
  - **Surface:** It calculates the surface of the objects in a binary volume (number of surface voxels). The user selects the input volume through the *Select Input Volume* dialog box and is notified for the measurement result.
  - **Volume:** It calculates the volume of the objects in a binary volume (number of voxels). The user selects the input volume through the *Select Input Volume* dialog box and is notified for the measurement result.
  - **Bounding Box:** It finds the bounding box of a volume (the smallest VOI containing non-zero voxels). The user selects the input volume through the *Select Input Volume* dialog box and is notified for the measurement result.

Transforms: This sub-menu includes the following operations:

- **FFT:** It performs the Fast Fourier Transform (FFT) of a volume. The user selects the input volume through the *Select Input Volume* dialog box and the real and imaginary parts of the complex output volume through the corresponding *Select Output Volume* dialog boxes.
- **IFFT:** It performs the Inverse Fast Fourier Transform (IFFT) of a volume. The user selects the real and imaginary parts of the complex input volume through the corresponding *Select Input Volume* dialog boxes and the output volume through the *Select Output Volume* dialog box.
- **DCT:** It performs the Discrete Cosine Transform (DCT) of a volume. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box.
- **IDCT:** It performs the Inverse Discrete Cosine Transform (IDCT) of a volume. The user selects input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box.
- **Convolution:** It calculates the convolution between two volumes. The user selects the two input volumes through two successive *Select Input Volume* dialog boxes and the output volume through the *Select Output Volume* dialog box.

- **Correlation:** It calculates the correlation matrix for two volumes. The user selects the two input volumes through two successive *Select Input Volume* dialog boxes and the output float volume through the *Select Output Volume* dialog box.
- **Spectrum magnitude:** It calculates the spectrum magnitude of a volume, suitably scaled and centered for visualization. The user selects the input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box.
- **Blackman Tukey PSD:** It estimates the Blackman Tukey Power Spectral Density (PSD) of a volume. The user selects input volume through the *Select Input Volume* dialog box and the output volume through the *Select Output Volume* dialog box and also gives the attenuation coefficients through the *Give attenuation coefficients* dialog box.

Morphology: This sub-menu includes the following 3D binary mathematical morphology operations, which require that a binary volume containing the 3D structuring element exists:

- **Minkowski addition:** It performs Minkowski addition of a binary volume with another binary volume considered as the structuring element. The user selects the input volume through the *Select Input Volume* dialog box, the output volume through the *Select Output Volume* dialog box and the Structuring Element volume through the *Select Structuring Element Volume* dialog box.
- **Minkowski subtraction:** It performs Minkowski subtraction of a binary volume with another binary volume considered as the structuring element. The same procedure as in **Minkowski addition** is followed.
- **Dilation:** It performs dilation of a binary volume with another binary volume considered as the structuring element. The same procedure as in **Minkowski addition** is followed.
- **Erosion:** It performs erosion of a binary volume with another binary volume considered as the structuring element. The same procedure as in **Minkowski addition** is followed.
- **Opening:** It performs opening of a binary volume with another binary volume considered as the structuring element. The same procedure as in **Minkowski addition** is followed.

♦ **Closing:** It performs closing of a binary volume with another binary volume considered as the structuring element. The same procedure as in **Minkowski addition** is followed.

Figure 5: An example of BW contour following at an image sequence of cross-sections of a tooth.

BW Contour Follow: The user can follow the contour of the objects of interest on each frame of a grayscale volume by using the mouse. The original volume is selected through the *Edge Follow Original Volume* dialog box and the output volume is through the *Edge Follow Output Volume* dialog box. The left mouse button is used to follow the contours and the right mouse button is used to correct the errors. The user operates on the original volume frames, whereas the contours are written in a second volume that is displayed as well, each time the displayed output volume frame corresponds to the input volume frame. The output volume is binary and the user is responsible for saving it. Usually, the output volume is intended for producing the surface representation of the input volume, which can be used for surface rendering. An example of BW contour following can be seen in Figure 5.

Color Contour Follow: This operation is the same as the previous, with the difference that the user can select a different color for every object by clicking with the right mouse button in the output volume window and a color output volume is produced. This enables automatic object discrimination. An example of color contour following can be seen in Figure 6.

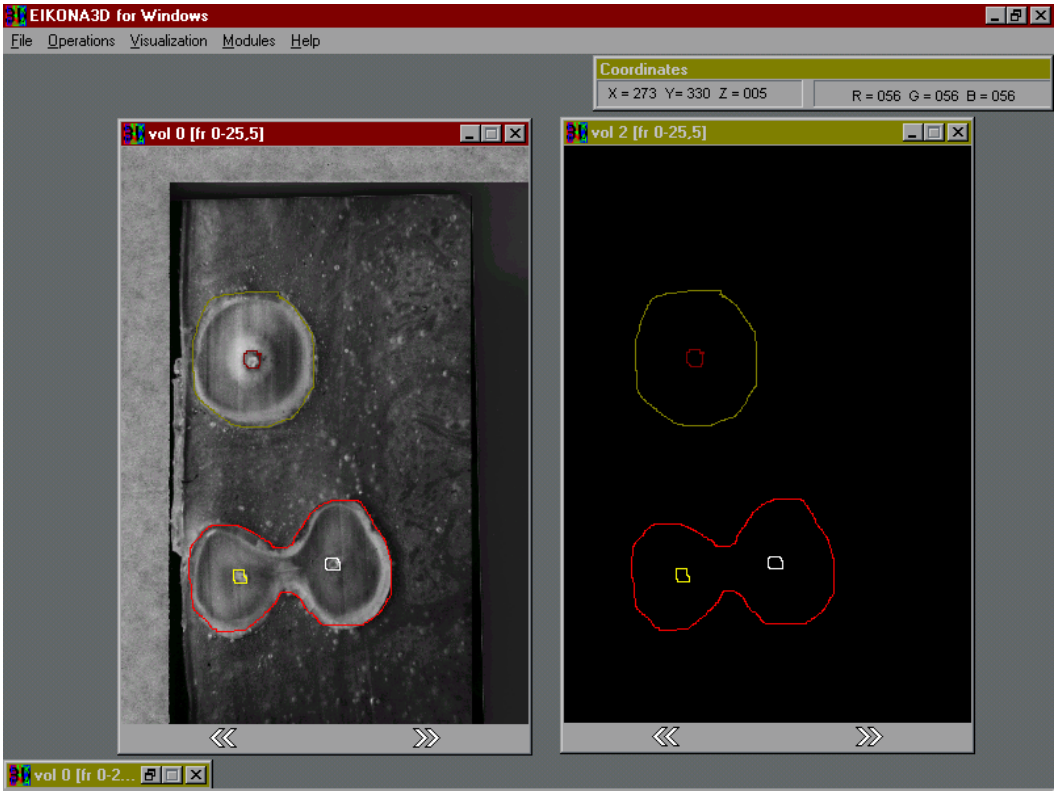

Figure 6: An example of color contour following at an image sequence of cross-sections of a tooth.

Manual Frame Alignment: This operation enables the user to align the image sequence frames by manually aligning each successive frame pair. The user selects the input volume (which contains the image sequence to be aligned) through the *Select Input Volume* dialog box, the output volume (in which the aligned image sequence is saved) through the *Select Output Volume* dialog box and the range of input frames to be aligned through the *Manual Alignment Options* dialog box. Then, the *Align ToolBox* is displayed, as well as a special window that visually leads the alignment procedure. This window presents both the current frame and its previous one (except from the first frame which is presented alone). Their discrimination is achieved by giving red color to the current frame and blue color to the previous frame. The *Align ToolBox* includes a number of buttons that enable the user to control the

alignment procedure. There are buttons for moving between the frames (*Next, Prev, First, Last*), for moving the current frame in respect to the previous one (*Left 1, Left 10, Right 1, Right 10, Up 1, Up 10, Down 1, Down 10*), for rotating the current frame in respect to the previous one (*cw 1, cw 5, ccw 1, ccw 5*), for resetting the changes to the current frame (*Reset Current*) or to all frames (*Reset All*), for saving the changes for the current frame (*Save Current*) or for all frames (*Save All*) to the output volume, and for quitting the alignment procedure (*Quit*). The movement/rotation of the current frame can also be performed by dragging the cursor with the left/right mouse button clicked inside the special window. The user must only be concerned with the alignment of the current frame to its previous one, since the absolute position of every frame is used (considering any changes made to it). The effects of all changes are reflected to the output volume after saving. The output volume can be previewed during the procedure with the visualization operations explained below, and the user is responsible for saving it to the disk. An example can be seen in Figure 7.

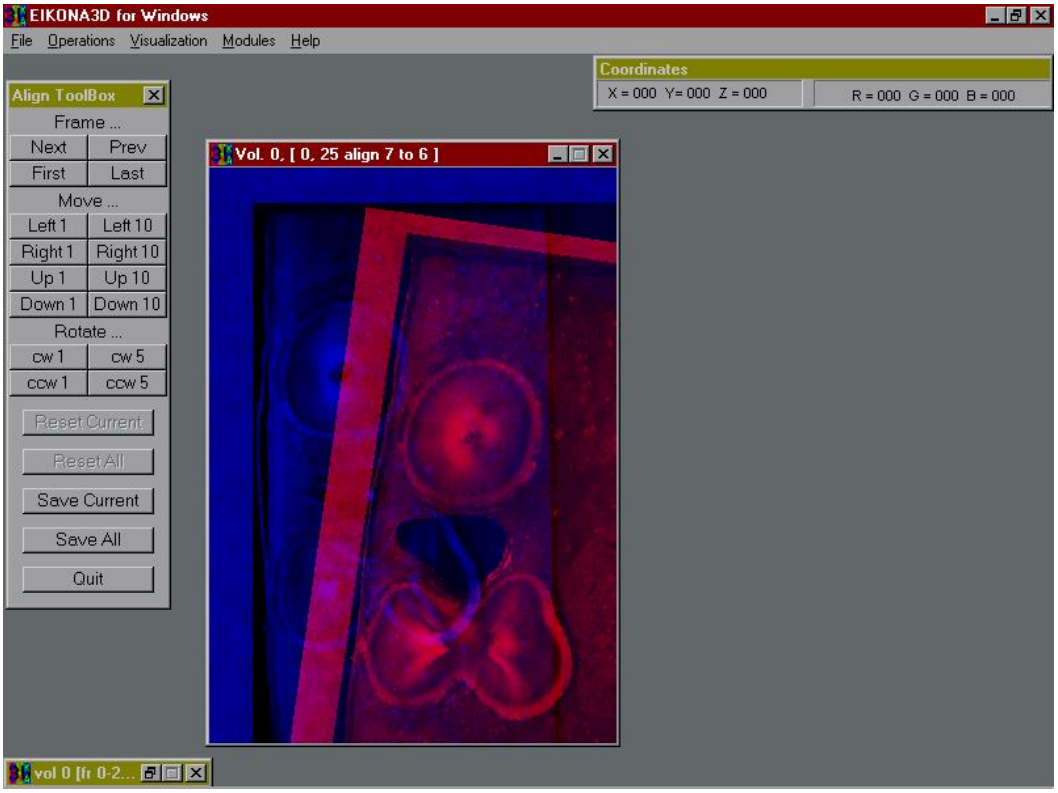

Figure 7: An example of manual frame alignment at an image sequence of cross-sections of a tooth.

4.3.3 Visualization menu

This drop-down menu provides several basic 3D visualization tools, based on an orthogonal sectioning of a volume. More complex 3D visualization tools that enable

the user to visualize and explore the inner structures of volumetric data, which is useful in several scientific fields such as Medicine, Biology, Geology etc., have been developed as additional modules (3D surface rendering, 3D volume rendering) and can be found under the Modules menu (if they are purchased). A view of the Visualization menu can be seen in Figure 8.

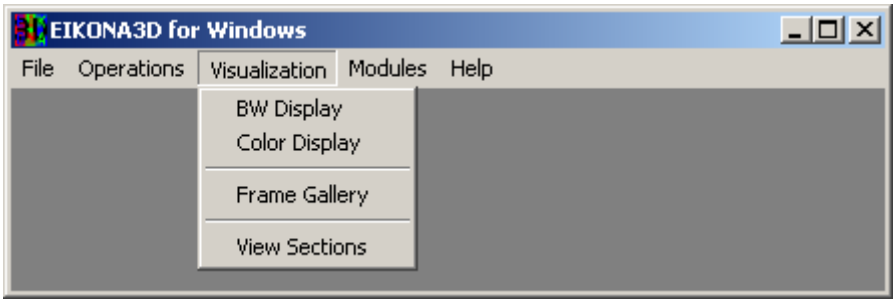

Figure 8: A view of the Visualization menu.

There are four menu options, which are described below:

BW Display: This menu option is used for visualizing the frames of a grayscale volume.

Color Display: This menu option is used for visualizing the frames of a color volume. In both the above options the user first specifies the volume to be displayed through the *Select Volume to Display* dialog box and the display mode through the *Get Display 3D Levels - Delay* dialog box. In the second dialog box, the user specifies the range of the volume frames to be displayed in the *Lower Display Level* and *Upper Display Level* fields and the continuous display rate in the *Display Delay* field. The display window (which is the same as the one that is displayed when you open a volume from disk) provides six buttons for moving between frames (backward one, backward playback, stop, forward playback, forward one, continuous loop playback). It can be moved, closed, minimized and restored as any other window. The display window title shows the number of the volume, the range of the displayed frames and the current frame. An example of a BW frame display can be seen in Figure 9.

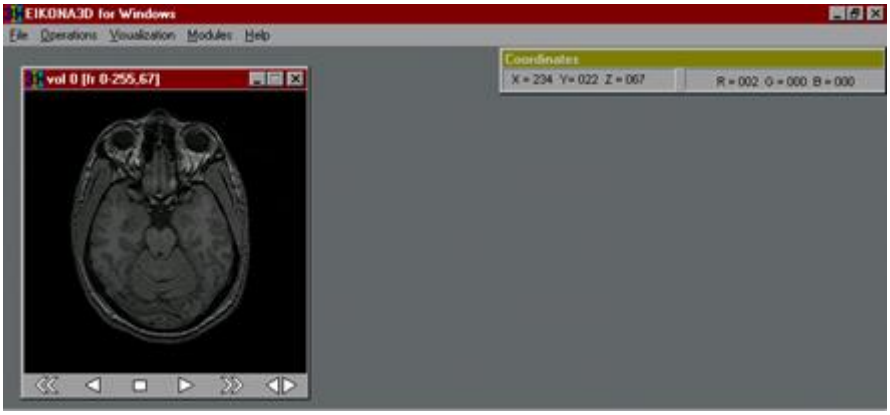

Figure 9 An example of BW frame display of an image sequence of cross-sections of a head.

Frame Gallery: This menu option is used for displaying the frames of a volume as a gallery image, that is one displaying all frames simultaneously one next to the other (usually in smaller size). The user first selects the input volume through the *Select Input Volume* dialog box. Then, he specifies the required parameters through the *Frame Gallery Display Options* dialog box, which are the frames per row in the output image and the interpolation method (Nearest Neighbor or linear) that will be used for the adaptation of the frame size. A default width of 100 pixels is used for the input frames in the output image. If the user clicks with the left mouse button on a specific frame in the frame gallery image, this frame becomes the current frame in any currently open display windows of the input volume. The output image in the frame gallery window can be saved in disk by selecting the **Save Image** menu option from its system menu. An example of frame gallery display can be seen in Figure 10.

View Sections: This menu option is used for simultaneously displaying the three orthogonal sections that intersect at an arbitrary point inside the volume. The user specifies the volume to be displayed through the *Select Volume to Display* dialog box. The produced window contains four subwindows; the upper left one displays the image of the section parallel to *xy* plane (which is one of the volume frames), the lower left one displays the image of the section parallel to *xz* plane, the upper right one displays the image of the section parallel to yz plane and the lower right one displays the co-ordinates of the reference point (*x*,*y*,*z*) at which the three sections intersect (which can change by clicking on any of the three images) and also contains three sliders by which the *x*:*y*:*z* factor can change. An example of section display can be seen in Figure 11.

In the lower part of the volume window is the *Play Bar*. It consists of buttons, which are responsible to play the sequence of the volume frames. More specifically, the meaning of the various buttons are as follows:

Move to the first volume frame,

Move the previous volume frame,

Stop to play the image sequence (volume frames),

Move to the next volume frame,

Move to the last volume frame, and

Play the image sequence (volume) back-and forth in a continuous mode.

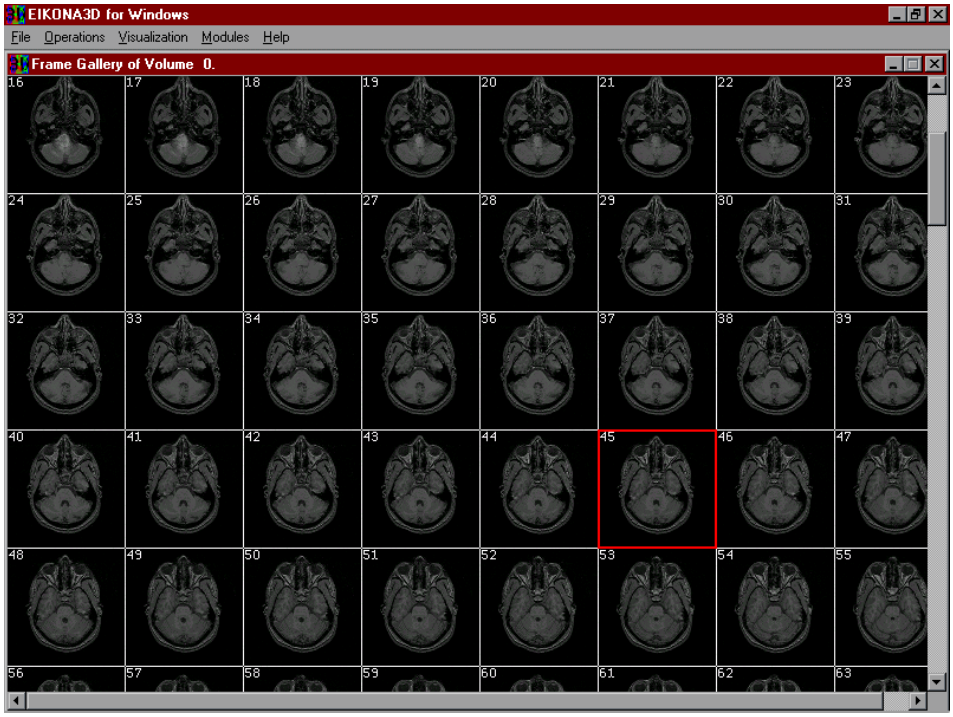

Figure 10 An example of frame gallery display of an image sequence of cross-sections of a head.

Figure 11 An example of orthogonal sections exploration procedure.

4.3.4 Modules menu

This menu provides a flexible expansion mechanism for incorporating additional modules in EIKONA3D by the developer or even by any user. Each such module adds a sub-menu under the **Modules** menu and should be developed in the form of a DLL (Dynamic Link Library) that follows certain rules, so that EIKONA3D can find all necessary information, such as its name and the structure of the sub-menu. The **Modules** menu is built dynamically when EIKONA3D starts, after examining all the module compliant DLLs that exist in EIKONA3D directory.

The EIKONA3D modules are described in detail in the Part II of this manual.

4.3.5 Help menu

This sub-menu provides the About… item which displays information about the program (see Figure 1).