Medical Images Illustrator - A Flexible Image Processing System

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Abstract— In this paper, we propose a medical image processing and visualization system, Medical Image Illustrator (MIIL), which is able to help doctors for symptom diagnosis, detection and surgical planning. MIIL can process and visualize the Digital Imaging and Communications in Medicine (DICOM) data directly. We have implemented some processing concepts, such as "dynamic processing flow", "dynamic flowing branch" and "multiple masks / images operation", which make MIIL a very flexible workbench for image processing. The system can also be easy extendable for different situations.

Dynamic processing flow enables MIIL to apply a variety of 2D and 3D image processing algorithms on images or masks to filter out some features. This can results in better images for analysis and segmentation. Dynamic flowing branch allows the user to create different process-flow on images or masks. Each flowing branch can apply different operations independently. Users can also perform operations on multiple flows, or combine the results from different processing-flow.

In the visualization stage, the 3D volume datasets are generated from different masks of 3D images. MIIL supports interactive direct volume rendering on multiple datasets, users can visualize these data with the ability to adjust the transfer function of each dataset individually. Therefore, MIIL could allow users to visualize and interact with multiple volumes that each volume represents different tissue or organ. Besides, MIIL also supports stereoscopic display, which is suitable for Virtual Reality (VR) application to enhance the visual effect.

With above features, MIIL can provide very useful and decent visual effect to display medical or other 3D images. We will give two examples which use MIIL to process data. In the first case, we use MIIL to process the CT data of human chest. We were able to find possible tumor tissues in the data and provide visual analytics to these tissues. In the second case, we use MIIL to process the T1 MRI and Diffusion Spectrum MRI (DSI) together, doctors are able to visualize the relationship between tumor, tracts and brain structure. Based on the above two successful cases, we believe that MIIL is helpful for diagnosis and surgical planning for a trained medical staff.

I.   INTRODUCTION

In recent years, with the pervasion of the Picture Archiving and Communication System (PACS), many software packages for medical image were developed on personal computer to help medical staffs for training, diagnosing, and even researching. The design issues of these software packages are supplying the image processing and analyzing functions as much as they can, while still to keep the software easy to use. Our proposed software system is called MIIL (Medical Image Illustrator). MIIL provides most of the features needed in the medical image processing and visualization pipeline from data import, image processing, display and navigation. We use the libraries, Image Toolkit (IMT) [16] and 3D VR Engine (3DVRe) [9] as the building blocks for MIIL. IMT is an image processing library for multi-channel 2D and 3D images. 3DVRe is a library for display, navigation, and interaction with the data processed by IMT.

MIIL has four important features: dynamic processing flow, dynamic flowing branch, multiple masks / images operation, and integrated visualization process. The mask means the region we want to segment or the region we have segmented; and the image means a series of grayscale or true color slice image. By dynamic processing flow, user can apply a series of image processing functions on a set of 3D images or 3D masks to enhance the image or to segment certain feature. By dynamic flowing branch, we can perform different procedures in each "dynamic flowing branch" and generate different sets of result masks and images. By multiple masks / images operation, user can perform operations on different masks or apply the mask to images from different flowing branch to optimize the segmentation results. In visualization process, user can visualize multiple tissues and organs. With above feature, MIIL have provided a very flexible pipeline for medical image processing and visualization.

In order to process the 3D image with higher resolution in the near future, MIIL was designed for cross-platform operating systems on both 32bit/64bit Linux and Windows, and the rendering engine of MILL also fully supports OpenGL 2.0 so it can take advantage of hardware acceleration of graphics card. Currently, we have two successful examples which use MIIL to obtain the results. The first one, we use MIIL to clarify the relationship between tumor and tissues in CT data of thorax. The second one, we depict the relationship of tracts, tumor and other structure inside a human brain by inputting multi-model of data from T1 MRI and DSI. Because of the two successful cases, we believe MIIL is a useful image visualization system for diagnosis, detection and surgical planning.

II. PREVIOUS WORK

We will discuss our previous works, which are the foundation of MIIL, in subsection A. We will discuss some important related works in subsection B.

A. Background

MIIL is based on an image processing library – Image Processing Toolkit (IMT) [16], and a rendering and visualization engine – 3D VR Engine (3DVRe) [9]. Both of them are written in C++ and platform independent. IMT supports many image formats including JPEG, DICOM, TIFF, and works on both 8bit and 16bit data formats. Beside 2D image, IMT supports 1D, 3D, and 4D images as well. 3D image is a stack of series 2D images, and 4D image is a time series of 3D images. The 3D image, which is usually known as volume, is the most popular data format for medical visualization. IMT has integrated many image processing functions, such as cropping, resizing, histogram analysis, fast Fourier transform (FFT), level set, watershed, and lazy snapping [8]. These features of IMT give users high flexibility to segment, register, and manipulate different dimensional images. To take advantages of current new generation multi-core CPUs architecture, we use OpenMP [4] to do the parallelization of IMT. It makes IMT more efficiently when running on the new generation PCs with multi-core CPUs.

3DVRe is developed in C++ with OpenGL 2.0 supported. 3DVRe is well configured to run as efficient as possible on current consumer PC with suitable graphics card. 3DVRe can take geometry objects and volume objects as input data, and it is special designed for rendering large terrain rendering and volume visualization. A multi-resolution scheme, called Level-Of-Detail (LOD), is implemented in this engine, so 3DVRe are able to interact with large data set. 3DVRe has stereo display capability as well. Thus, hybrid rendering of geometric objects, volume data, and terrain models in a Virtual Reality (VR) environment can be done easily. 3DVRe also have other convenient features, such as XML-based scene description, 3D text with TrueType font support, and the support for user specified key binding.

Many image processing functions from IMT and texture-based volume rendering [2, 3, 6] with pre-integration [5] from 3DVRe are used in MIIL. In this system, we design a processing procedure for medical images and provide graphical user interface for these functions using FLTK [15] to increase the usability for a trained medical staff.

B. Related Work

The alternative choice to process and visualize medical data is to use VTK and ITK. VTK is the visualization toolkit designed by Kitware [14]. It is a very powerful visualization library which has built in many common visualization functions. However, it is relatively difficult if we need to speed up the performance by adding some custom features that need to take advantage of graphics hardware.

ITK is Insight Segmentation and Registration Toolkit [7] developed by the National Library of Medicine. It provides a lot of useful tool for segmentation and registration on medical images, but it has the same problem as VTK that it is not easy to integrate some graphic hardware specific codes into it.

There are also some commercial software packages for medical image processing; one of the most popular tools is Amira [1]. Amira has abundant functionalities to perform image processing and visualization. But it is expensive; and users have to pay separate license fee for different capabilities, such as for VR display, or use its SDK to create plug-in functions. Another issue is that you still have to write your own code with Amira SDK if you choose to visualize your data by applying new algorithm or new graphics hardware features.

There are some free tools available. Julius proposes a medical application framework for image processing, visualization, and surgical planning [13]. Unfortunately, its techniques for segmentation and visualization are outdated, and these functionalities are not supported by graphics hardware features which are critical to get good quality and performance while doing image processing and rendering. MRIcroN is another good tool to process and visualize medical images, especially MRI images [12]. Although many image processing functions for MRI images are supported, MRIcroN is weak on the visualization part and it can only support a few file formats.

III. SYSTEM OVERVIEW

MIIL is developed to integrate the whole pipeline from medical image processing to visualization, including the data import, image processing, visualization and navigation. Figure 1 shows the working model of MIIL. We use IMT, 3DVRe and FLTK to construct the MIIL. IMT and 3DVRe are the libraries developed by the visualization team at NCHC. And FLTK is an open source GUI toolkit.
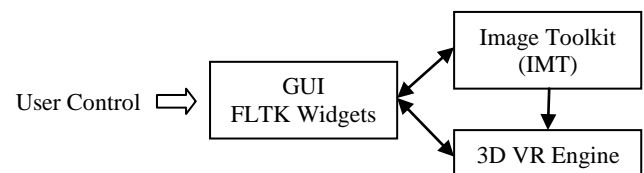

Fig. 1. MIIL Overview

IMT provides many image processing functions and supports a variety of image file formats. The 3DVRe has feature for interactive volume visualization. It accepts a series of images processed by IMT and display these 3D images using direct volume rendering method. The user interface is built on FLTK to allow users to manipulation the image and adjust display parameters.

MILL can load a stack of 2D images as a 3D image. The formats could be TIFF, JPEG, BMP, or DICOM, and the pixel data can be 8bit or 16bit. After loading the image data, users can use the functions provided by MIIL to do segmentation and MIIL will generate a set of masks to mark different regions or segments.

MIIL retains the flexibility by introducing the dynamic processing flow, dynamic flowing branch and multiple masks

/ images operation and has an integrated visualization flow in pipeline. More detailed explanations about these features will be described in the next section.

IV. SYSTEM FEATURES

In this section, we will describe the detail about the four major design concepts of MIIL: dynamic processing flow, dynamic flowing branch, multiple masks / images operation, and a visualization flow on 3D Images.

In traditional image processing packages, user perform different image processing function sequentially to get the final results. However, in some cases we will have to apply different image processing exclusively to separate different segments and then combine the separate outcome to get the final result. The traditional sequential operation is not suitable for this case.

To solve above problem, we introduce Dynamic Processing Flow, Dynamic Flow Branch, and multiple mask/image operations in MILL. It will give user a lot of flexibilities while processing the images..

A. Dynamic Processing Flow

In figure 2, it shows the concept of dynamic processing flow. User can apply image processing algorithms on 3D image or mask, and the result will be stored for further processing. In dynamic processing flow, we can perform different image processing functions as many times as necessary.

In addition to process 3D image directly, MIIL can treat the 3D images as a series of 2D image, so MIIL can apply the 2D image processing algorithms on individual slice. In this part of pipeline, MIIL can repeatedly apply 2D or 3D algorithms on the image data with different parameters until the users obtain satisfactory result.
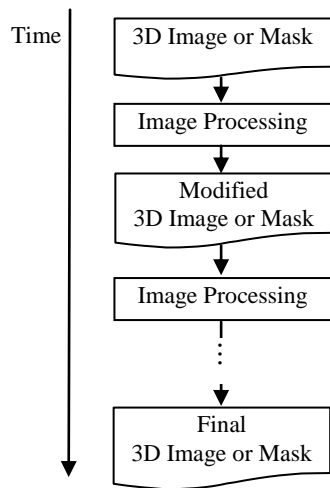

Fig. 2. Dynamic processing flow

B. Dynamic Flowing Branch

It happens often that a sequence of image processing algorithms with a set of parameters might enhance some characteristic but blur another. The concept of Dynamic flowing branch is that user can create branches and each branch has its own 3D image buffer. Each branch is an individual dynamic processing flow. User can apply different image processing functions individually or combine images from different flows, as what is shown in figure 3. User can request as many branches as they want; the limit of branches is bounded by the system memory.
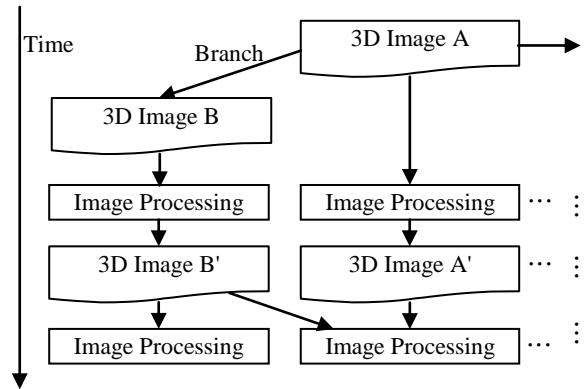

Fig. 3. Dynamic flowing branch

In Fig. 3, after requesting for a new branch, there are two buffers for two image dynamic processing flow, one for 3D image A, and one for 3D image B. The works on these two branches are independent. We can enhance a characteristic on 3D Image A in the first flow and enhance the other characteristics on 3D Image B in another flow. Then we combine the results from these two process flowing branches to have all the desired characteristics shown.

C. Multiple Masks / Images Operation

MIIL provides multiple branches for images processing and it provides maximum eight 3D image masks for labeling. The 3D image masks are used for storing the region of interested characteristic in input image, such as a segmentation of an organ inside human body.

In MIIL, we can apply operations on the images of different flowing branches, such as merge, compare, just like what we had presented in the previous subsection. For the masks in different branches, user also can apply binary operations between masks, such as "and", "or", "xor", and "subtract". Users can map the mask created in one branch to the images in the other branch, so user can generate a mask from an image and continue process it with another image.

Figure 4 is an example of multiple masks / images operation. We create two flowing branch, one has mask A and the other has mask B. Both masks are from 3D Image C. Then we apply 3D seed growing algorithm to segment different characteristics on each branch and the results are mask A' and mask B'. Then we map mask A' to 3D Image E in another flowing branch to revise the mask by applying other segmentation algorithms. And mask B' also can map to 3D

image D in another flowing branch for different segment result. Finally, user can combine the results, mask A" and mask B", to get the final result, final mask A.
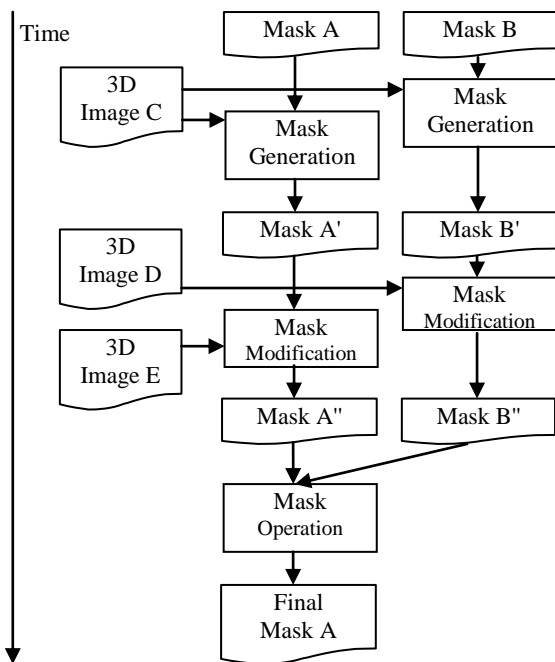

Fig. 4. Multiple masks / images operation

We called this feature as multiple masks / images operation. By this feature, user can generate and modify the masks of 3D image in different processing flows and get the desired classification result for the specified characteristic. With the masks, we can also calculate the area of the region of the mask or measure the volume size of the marked tissue.

D. Visualization Flow on 3D Images

After the segmentation is completed, MIIL can render the results on the screen by direct volume rendering. MIIL is able to render multiple volumetric data.

As show in figure 5, there are total n+1 volume datasets which n represents the number of the masks used, and the 1 is the original 3D image in a selected dynamic process flow. In this case, each flowing branch performs crop operation for different characteristics to segment different region. And different volume data were generated from the masks for each region of different flowing branch. Finally, MIIL will render all the volumes together to show the final result.
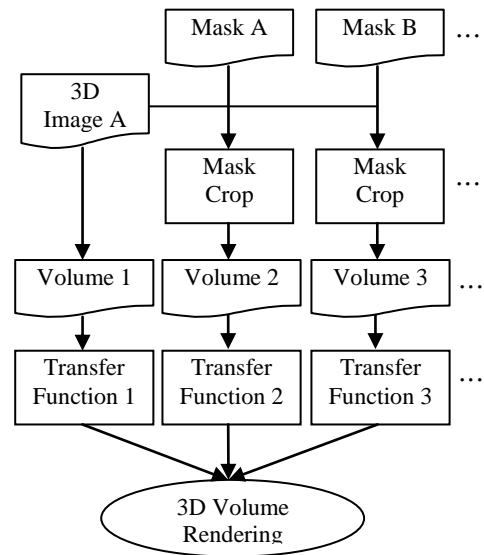

Fig. 5. Visualization Flow of 3D Image

During volume rendering, MIIL provides the functionality to let user adjust the transfer function for each volume dataset. The transfer function maps the intensity value in images to a user specified color range. User can adjust the color of different volume to enhance the visualize effect. Not only color, but also the opacity value of each volume is adjustable. User can also navigate through multiple volume datasets concurrently to observe the relationship among volumes.

V.   RESULT

In this section, we discuss two successful cases processed by MIIL. The first case we use MIIL to assist the diagnosis and the surgical planning for lung cancer. In another case, MIIL is served as a training tool and it created a video for educational purpose by visualizing human brain and brain neural fibers.

A.   Diagnosis and Surgical Planning for Lung Cancer

From the USA report of cancer statistics [17], lung cancer is the top one fatal cancer in worldwide. Traditional training for lung cancer diagnosis is based on the observation of a series of thorax CT images by doctors. Doctors have to judge tumors' location and size in these 2D images and build up the 3D relationship of different organs in their mind. This practice has some drawback and blind spot. Thus, it is helpful if we have a convenience system to help doctors diagnose lung cancer and create a like-real environment to let doctors prepare surgical plans.

Our focus is on developing a semi-automatic lung cancer detecting software to alarm the doctors about the possible abnormal tissue based on the CT data. This software system will also visualize the CT data in 3D display or VR environment, and it can be used for monitoring the progress of treatment.

In order to perform the 3D Diagnosis as mentioned before, we will encounter one classification problem. In 3D environment, we usually use the mapping between intensity

and color as transfer function (TF) to classify input data. However, the intensity value of cancer and thorax are too close. Thus, we provide a novel segmented classification method which can be easily achieved by MIIL to solve this problem [10]. We segment lung from thorax, and then give lung and thorax volumes different transfer functions. This method avoids the collision of intensity values. Another benefit is that we can highlight tumors rounded by thorax.

Based on the previous idea, our procedure is designed as shown in figure 6. There are two major blocks: pre-processing and post-processing. In the pre-processing step, thorax images are segmented and then lung images are extracted. The MIIL system also provides tools for measuring the size of the segmented objects, like the 3D region growing in a stack of images. After diagnosis, in post-processing step, a texture-based volume rendering are used and doctor can see the result of diagnosis immediately. Therefore, users can interactively diagnose tumors and plan surgery in 3D or VR environment in MIIL.
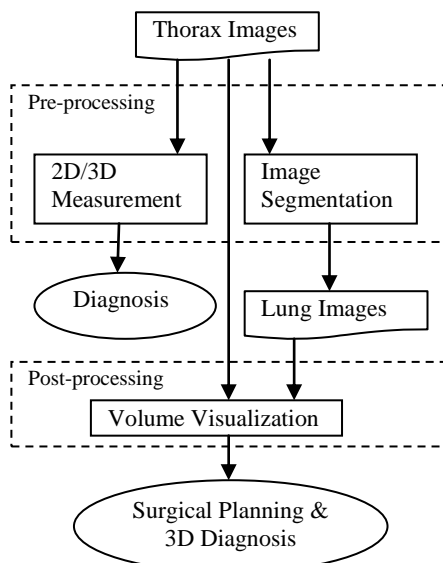

Fig. 6. Procedure for lung cancer diagnosis and surgical planning.

Figure 7 presents the detailed steps of segmentation procedure in the pre-processing stage. In this stage, we use dynamic processing flow to segment lung images from thorax images.
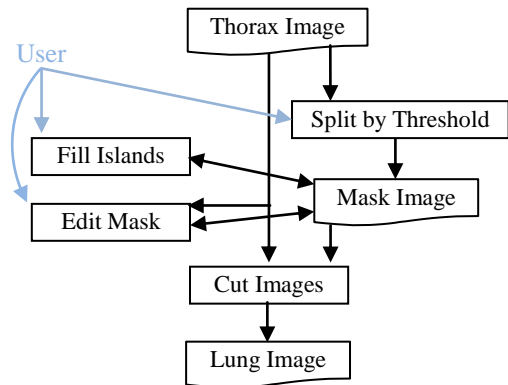

Fig. 7. Procedure of segmentation.

In order to generate the mask for segmentation, there are three main processing steps. The first step, we choose a threshold value to generate a lung region mask from the thorax CT scan because the intensity value of thorax is usually higher than the intensity value of lung. We will not get a perfect lung region mask at this step because the intensity of vessels or tumors is usually higher than the chosen threshold. Therefore, we apply the second step, using morphological closing algorithm with rolling ball to fill the holes in those 2D mask images. After the second step, we usually get an almost perfect lung region mask.

However, there might be some error when the tumors in the input images are too large or next to thorax. In the third step, we can edit those images interactively using MIIL. This processing procedure is an application of dynamic processing flow on masks. MIIL provides many kinds of mask modify methods with UI, such as seed growing, lazy snapping, or draw manually. User can repeat mask generation and modification procedure in different flow and combined them to get the best result finally.

In the post-processing stage, we use visualization flow on 3D Images to display the results. Figure 8 shows a snapshot of the volume rendering result. In this case of visualization flow, we have two volumes to display. One is image of thorax and another is image of lung which was the result we obtain in pre-processing stage.

Using MIIL, we can easily assign different transfer functions to different volumes. In this case, the bones in thorax volume, the lungs, the airways, and the tumors in lung volume were all highlighted in different color. The doctor can use MIIL as the tool for data browsing, diagnosis, and surgical planning in 3D or VR environment.

Fig. 8. A example of 3D diagnosis and surgical planning.

B. *Visualize Human Brain and Brain Neural Fibers*

The main focus of this case is how to handle the image data from different scan techniques within MIIL. There are different tissues in human body and each tissue has different attributes, we will need different medical image acquisition methods and devices to obtain the clear images of tissues and organs. We have brain tumor image data from different acquisition methods in this case, such as T1-weighted, T1 with reagent (T1+C), T2-weighted images, and Diffusion Spectrum MRI (DSI). T2-weighted images can make tumors in brain more clear. DSI is a novel technology that can identify tracts which are neural fibers in the brain.

Fig. 9. From left to right: T1 Skin, T1 Brain, DSI tracts, T1+C tumor.

In figure 9, it shows some visualization results of different data types. These imaging techniques show different lesion and have their own advantages and disadvantages. To make these images useful, we have to fuse them together. So how to fuse these images is the major task to tackle. Figure 10 presents the details about the complete pipeline how we processed all these data.
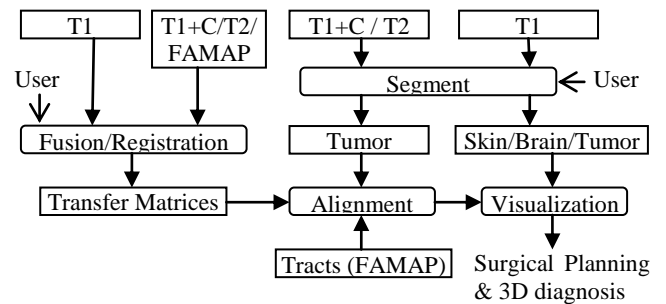

Fig. 10. The pipeline of processing the data from different scans

MIIL provides many tools for segmentation, such as seed growing (figure 11) and lazy snapping [8]. By these functions, they help us cut out the skin and tumor in the T1 and T2 images; moreover, we have also used gradient or edge detection function in MIIL to identify skin contour and brain contour easily (figure12).
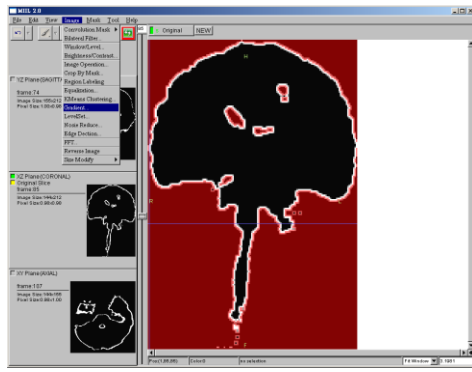

Fig. 11. 3D seed growing UI and result.

Fig. 12. Result of Gradient.

By dynamic flowing branch and multiple masks / images operation, we can apply operations between different images and apply the mask generated by one image and map it to the original image, this help us get a better skin and brain contour and still keep the details of them.

Our system also provides a convenient interface for the user to cut out the required part of the image semi-automatically, and supply functionalities of fusion and registration. By applying the registration matrices from the previous step, these images will be aligned to the correct position in 3D space and we can then present the fused result. It helps doctors make more understanding of the relationships between tumor and surrounding tissues, and doctors can make better surgical plans. Brain science researchers can also use our tool to do their research, and it could also be used for educational purpose.

In this phase, we load T1 as the reference image (upper left in Fig. 13), and load other 3D images, such as T1+C, T2 or Fractional Anisotropy Map (FAMAP), as the target image (lower left in Fig. 13). User can see the preview of the fusion result on the interface (upper right in figure 13) by apply the specified parameters. User could draw two red rectangles in the two image-boxes to pick up the area you want to fuse automatically. Otherwise, user can also mark some correspondent landmarks on two image-boxes to fuse two images.
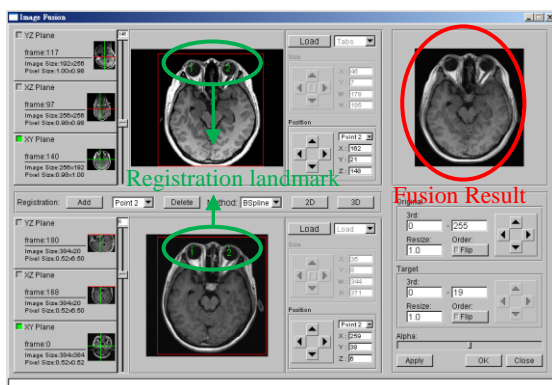

Fig. 13. Fusion and Registration UI.

By the transformation matrices from fusing images, the relevant data (e.g. T1+C, T2 or FAMAP) could be mapped to the correct position in 3D space. Finally, we can align the coordinate of tracts in 3D space using the correspondence position between three reference images of tracts and FAMAP.

Fig. 14 shows the result when different data have been aligned together. As we can see, the tracts are deformed by a tumor. This 3D presentation could provide better observation for the medical researchers and doctors to make more accurate plans before surgery, to avoid the affection on tracts of the patient, or to help them make progress in the studies of brain science and applications.
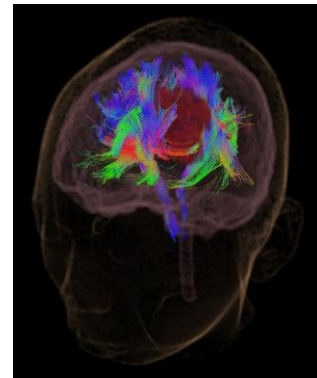

Fig. 14. Visualize Result.

VI. CONCLUSION

The proposed MIIL supports a full medical image processing pipeline. It can read the DICOM and many general types of image files and process it directly. In MIIL, we designed the concepts of dynamic processing flow, dynamic flowing branch, and multiple masks / images operation to help users processing images more easily. And MIIL have also integrated visualization flow to let users view the processed images immediately. MIIL give users a flexible 3D medical image processing platform. According to these features, we can achieve the goal to use manual or semi-auto methods to edit, segment, and visualize 3D images. With good segmented images, they can be visualized by volume rendering in MIIL clearly. For measurement, a doctor can monitor the evaluation of a tumor and estimate its size more accurately. Based on 3D visualization and navigation, a surgeon can obtain a pictorial image instead of imagination for surgery planning or training. We believe that MIIL can be a useful tool to help the medical professional to improve the diagnosis and planning, it can also be a good help in medical researches.

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