MITK & 3DMed : An Integrated Platform Applicable for the Development of Computer Assisted Intervention Systems

Release 1.00

Jie Tian, Yakang Dai, Kexin Deng, Jian Zheng and Xiaoqian Dai

June 28, 2008

Medical Image Processing Group, Institute of Automation, Chinese Academy of Sciences.
E-mail: tian@ieee.org, Tel: +86-10-82618465, Fax: +86-10-62527995.
P. O. Box 2728, Beijing 100190, China.

Abstract

This paper introduces an integrated 3D medical image processing and analyzing software platform which is open interface and freely available. The platform consists of the Medical Imaging Toolkit (MITK) and the 3-Dimensional Medical Image Processing and Analyzing System (3DMed). MITK is an algorithm toolkit for research and software development, while 3DMed is a MITK based application system with a plug-in framework. The overall architecture and main capabilities of the platform are described in detail. Presented evaluations demonstrate that the platform can benefit the development of computer assisted intervention systems.

Contents

1 Introduction

Accompanying with the development of modern computer science and technology, medical image processing and analyzing technologies are more and more attractive, which can provide more accurate and vivid information to assist clinicians in diagnoses and surgeries. Algorithms such as reconstruction, segmentation, registration, visualization, and interaction are the essential drives of medical image processing and analyzing. Many algorithms were developed in this field by scientists and engineers in the past two decades, and recently new algorithms have been emerging continuously. Based on existing algorithms, many software platforms, such as VTK (Visualization Toolkit) [5] and ITK (Insight Segmentation and Registration Toolkit) [3], were developed. Properly, these software platforms can be praised as accelerators of medical image processing and analyzing technologies. Making use of existing software platforms, users can implement new algorithms, develop practical application systems, or accomplish their work directly. Without re-implementing numerous mature algorithms, users can greatly quicken outcomes.

Current medical image processing and analyzing software platforms can be divided into two categories: one is the algorithm toolkit encapsulating all kinds of algorithms, which can provide an abundant algorithm library for software development, the other is the application system assembling plenty of algorithms and possessing friendly user interfaces, which can provide a wieldy computer assisted tool for practice. VTK and ITK are the most notable algorithm toolkits, while 3DVIEWNIX [7] and Analyze [1] are two typical application systems. To speed up implementations of advanced medical image processing and analyzing software platforms, many algorithm toolkits and application systems, such as Medical Imaging Interaction Toolkit [9], VolView [8], and Image Guided Therapy Toolkit [6], are developed based on existing outstanding software platforms.

Great importance has been attached to developing high quality medical image processing and analyzing software platforms. A particular workshop called *Software Development Issues for Medical Imaging Computing & Computer Assisted Interventions* was carried out in the conference of MICCAI 2003. Then *Visualization Toolkits Sessions* were held in SPIE Medical Imaging in 2004 and 2005. Recently *Medical Image Analysis with ITK and Related Open-Source Software Courses* were held in SPIE Medical Imaging in 2006 and 2007. At hand, the exciting workshop on *Systems and Architectures for Computer Assisted Interventions* in MICCAI 2008 is to be held. Nowadays, development of medical image processing and analyzing software platforms is becoming a hot topic. Unfortunately, there is no uniform software platform for medical image processing and analyzing till now. To satisfy the increasing requirements of researches and clinical applications for computer assisted tools, more and better software platforms need to be developed.

In this paper, we introduce an integrated 3D medical image processing and analyzing software platform, including MITK and 3DMed, which can be used for developing practical computer assisted intervention systems. An overview of this platform is presented in Section 2. The details of MITK and 3DMed are described in Section 3 and Section 4 respectively. Evolutions of the platform are exhibited in Section 5. Finally, we make conclusions in Section 6.

2 Overview of the Platform

As we konw, VTK and ITK are very popular in medical image processing and analyzing. However, ITK does not provide the function of visualization by itself and VTK is mainly devoted to general visualization, so we have to apply both ITK and VTK to develop a computer assisted intervention system. Nevertheless, VTK possesses the classical object-oriented design method where ITK possesses Generic Programming, consequently, the frameworks and coding styles of VTK and ITK are quite different. From a normal user's

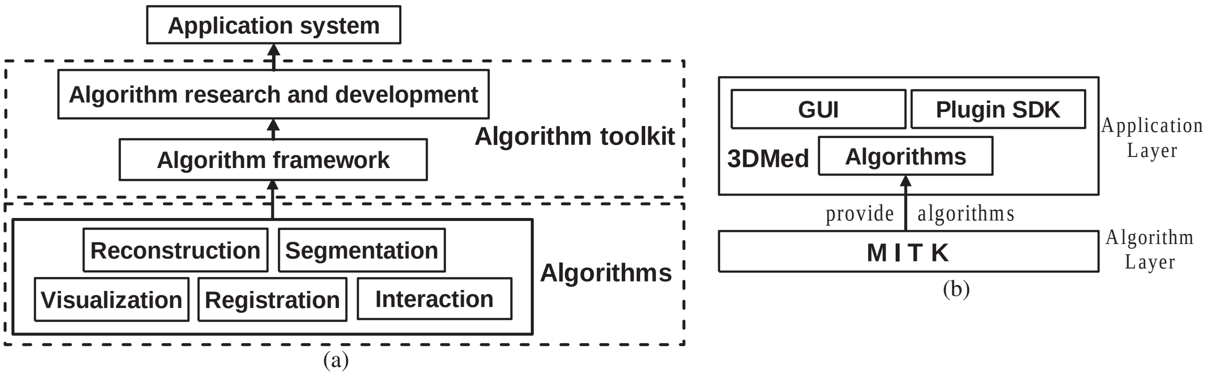


Figure 1: The total architecture of the platform. (a) The design solution; (b) The software implementation.

point of view, it is difficult to handle two sets of large scale toolkits with very different styles. Besides, most existing software platforms, including VTK and ITK, do not provide the support to process out-of-core data sets which appear more and more these years. Without an underlying processing framework for out-of-core data sets, developers have to design special data accessing operations additionally. Our platform is investigated and developed specially for medical image processing and analyzing, which can solve the aforementioned problems and provide another proper platform for developing computer assisted intervention systems.

The total architecture of the platform is illustrated in Figure 1. As shown in Figure 1(a), we integrate the mainstream algorithms of medical image processing and analyzing, including reconstruction, segmentation, registration, visualization, interaction and so on, within a uniform algorithm framework to produce a powerful algorithm toolkit, which makes the platform focused and expert for medical image processing and analyzing. Based on the algorithm toolkit, an advanced application system can be developed conveniently. The implemented software consists of two layers, as shown in Figure 1(b). MITK is the fundamental layer which implements the algorithm toolkit, and 3DMed is the topper layer which implements the application system. MITK and 3DMed are combined together to form an extensible application system. Moreover, MITK can also be used solely as an integral algorithm toolkit like VTK and ITK.

3 MITK

MTIK is not based on other toolkits such as VTK and ITK, but a novel toolkit which provides the mainstream algorithms of medical image processing and analyzing. Some excellent features of existing algorithm toolkits are used for reference, while the whole framework and underlying algorithms of MITK are designed, implemented and optimized independently. All the codes in MITK are written in ANSI C++, and the Operation System (OS) dependent codes are as separated and minimized as possible. Currently MITK can be compiled on most mainstream C++ compilers and can run on multiple Operation Systems such as Windows and Linux.

Computational Framework: As same as VTK and ITK, MITK employs the data flow model to design the computational framework. As shown in Figure 2(a), a medical data is abstracted to a **Data** class [1], while an medical image processing algorithm is abstracted to a **Filter** class which receives an input data and generates an output data. A series of processing algorithms can be connected into a pipeline and form a flowing computational framework. Each **Data** is also connected to the disk cache and encapsulates the operations of data exchange between internal and external memories. It gives the capability of processing

[1] All classes in MITK are derived from the class **Object**

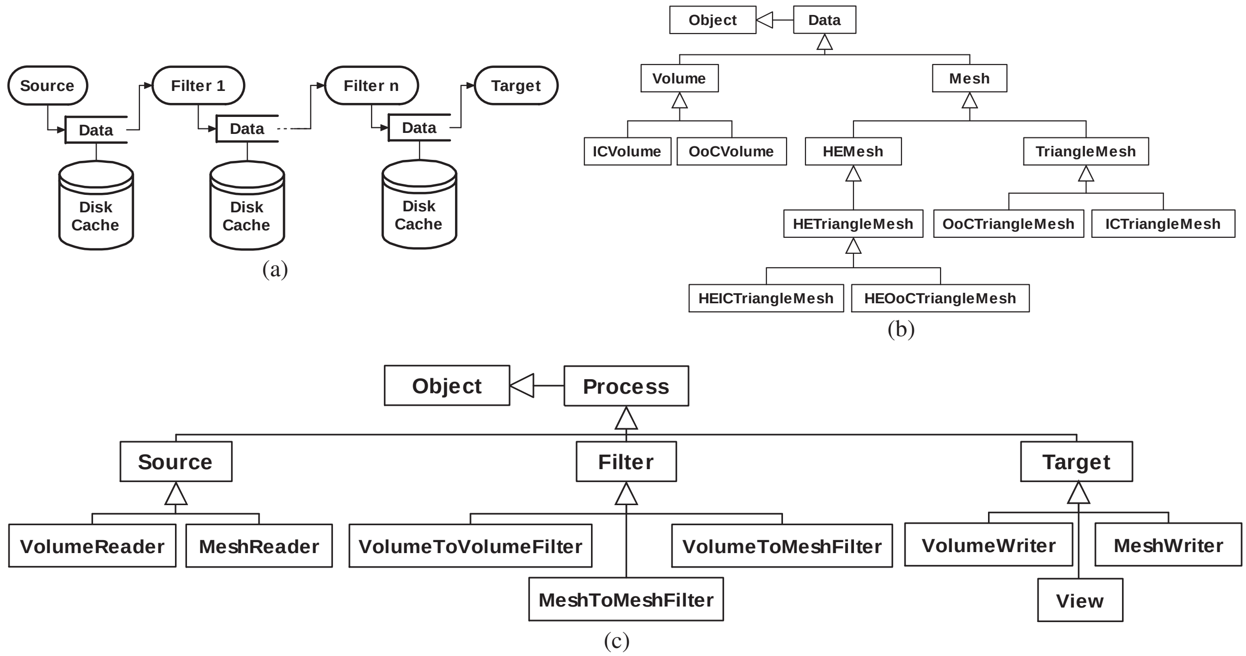


Figure 2: The computational framework of MITK. (a) The pipeline of data and processing algorithms; (b) Data model; (c) Processing algorithm model.

out-of-core data to this computational framework, which is not supported by most mainstream algorithm toolkits yet.

As shown in Figure 2(b), **Volume** and **Mesh** are two concrete subclasses of **Data** and represent two different kinds of data respectively. **Volume** demonstrates the multi-dimensional (1, 2, 3), multi-modal (such as CT and MRI) and regular medical image data. **Mesh** is a geometrical data which provides an abstract for three dimensional triangular meshes. Besides triangle, half-edge is also used in MITK as internal data structure of **Mesh**. **Volume** and **Mesh** implement the operations of out-of-core data access.

Source is a type of algorithm whose purpose is to generate the initial **Data** to start the whole processing pipeline. Concrete subclasses of **Source** include **VolumeReader** and **MeshReader**, which read data from disk and generate **Volume** or **Mesh**. **Target** is a type of algorithm whose purpose is to put the final **Data** to appropriate location and finish the execution of the whole pipeline. Concrete subclasses of **Target** include **VolumeWriter**, **MeshWriter**, and **View**, which write final results to disk files, or display final results onto the screen. Currently MITK can access most medical image file formats (DICOM, IM0, RAW, etc.) and two popular mesh file formats (PLY and STL). Most medical image processing and analyzing algorithms can be abstracted to **Filter**. As shown in Figure 2(c), **VolumeToVolumeFilter**, **VolumeToMeshFilter**, **MeshToMeshFilter** are three abstract subclasses of **Filter** and represent three different kinds of algorithms respectively. Concrete subclasses of **VolumeToVolumeFilter** implement algorithms such as reconstruction, image processing, segmentation and registration. Concrete subclasses of **VolumeToMeshFilter** implement surface extraction algorithms. Concrete subclasses of **MeshToMeshFilter** implement algorithms such as mesh simplification and mesh fairing.

Visualization and Interaction Framework: The visualization and interaction framework of MITK is shown in Figure 3. Each displayed object in the scene is abstracted to a **Model** whose subclasses are **DataModel** and **WidgetModel**. **DataModel** is the object controlled by **WidgetModel**, which consists of **VolumeModel**, **SurfaceModel** and **ImageModel**. They are respectively the encapsulations of volume, mesh, and 2D image. **View** is used to display all **Model**s in the scene, capture and distribute mouse messages. **Manipulator** is a

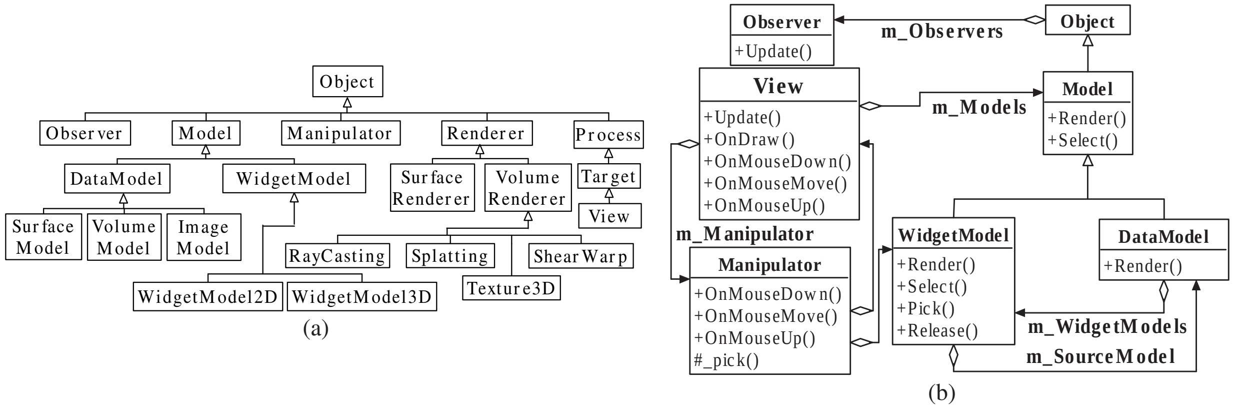


Figure 3: The visualization and interaction framework of MITK. (a) The inheritance hierarchy; (b) The class diagram.

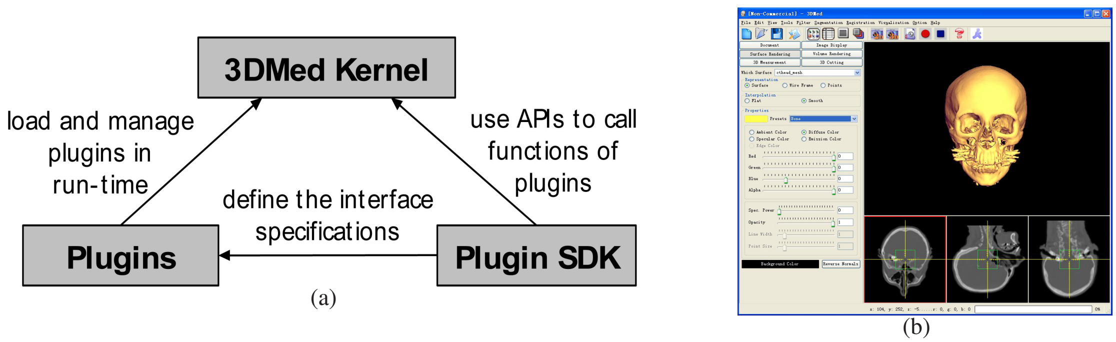


Figure 4: The overview of 3DMed. (a) The plug-in framework; (b) The main GUI.

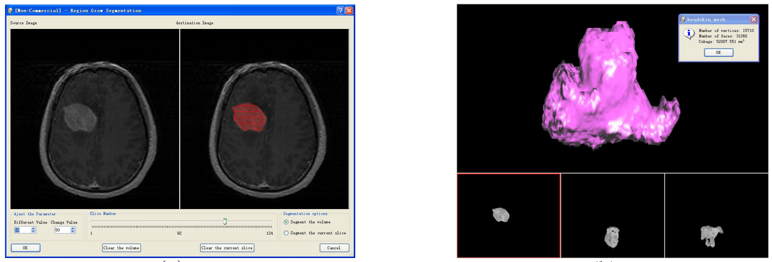
bridge class which receives the mouse messages captured by **View** and then drives **WidgetModel** to control the **DataModel**. Furthermore, a class named **Observer** is used to observe a **Model** and reflect the changes of the **Model** in time.

4 3DMed

3DMed is also coded with ANSI C++. It makes use of numerous algorithms provided by MITK to implement various medical image processing and analyzing functions, and employs Qt (a cross-platform GUI tool) [4] to design friendly user interfaces. Besides, 3DMed adopts the plug-in mechanism to reduce the coupling among different function modules and provide users an open, extensible application framework.

Plug-in is a dynamic link library written with certain specifications and can be dynamically loaded by the of kernel 3DMed. The plug-in framework of 3DMed is shown in Figure 4(a), where **3DMed kernel** is the core of the system with responsibility for loading, managing and calling each plug-in. **Plugin SDK** is the interface specifications for writing plug-ins. With these obligatory interfaces, the **Plugins** which is the actual plug-ins for practical functions can be identified and loaded by the kernel.

The main GUI of 3DMed is shown in Figure 4(b). The basic functions of 3DMed include data I/O, 2D manipulation, medical image segmentation and registration, 3D visualization and measurement, virtual cutting and so on. The 2D manipulation, virtual cutting and 3D measurement are implemented in kernel. The kernel also involves the basic visualization functions including surface rendering and volume rendering. Other functions are dynamically loaded through plug-ins. Several primary functions are briefly introduced as follows.



(a) (b)

Figure 5: Extraction of the tumor in the brain. (a) Segmentation with the region growing algorithm; (b) The segmentation and surface rendering results.

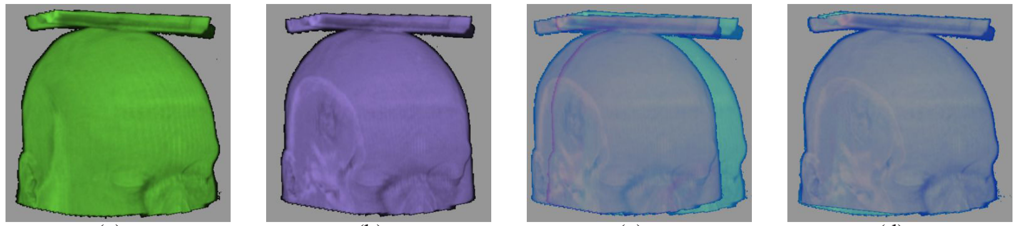
Segmentation: use plug-in mechanism to provide various segmentation algorithms, users can add new algorithms by their own plug-ins. ***Registration***: use plug-in mechanism to provide various registration algorithms and a modularized framework for assembling new registration algorithms. ***Surface Rendering***: use an enhanced Marching Cubes algorithm (based on segmentation) to get iso-surfaces and render them by OpenGL with hardware acceleration. ***Volume Rendering***: display volume images directly by using volume rendering algorithms, such as ray casting, splatting, shear warp and so on, and provide a set of wieldy interfaces to adjust transfer functions. ***Virtual Cutting***: support virtual cutting in both surface rendering and volume rendering with arbitrary planes, which enable users to have a clear view of the tissue and organs. ***3D Measurement***: provide various 3D widgets for the user to measure arbitrary areas, distances, and angles in the volume.

5 Evaluations of the Platform

A group of experimental examples are performed on a Windows-PC with an Intel Core2 1.86GHz processor and 1GB physical memory to evaluate the platform. Figure 5 shows a tumor extraction example with 3DMed. Firstly, we select a key slice in the volume image where the tumor is distinct enough, and specify a tumor seed in the slice. A 3D region growing algorithm is then used to segment the tumor. Finally, the surface of the tumor is extracted from the segmentation result with an enhanced Marching Cubes algorithm, and the cubage of the tumor is calculated automatically. Figure 6 shows a registration example with MITK. We use a rigid registration algorithm, which is based on intensity-based mean square difference metric, gradient descent optimizer and linear interpolater, to register two different volume images of the same brain. The registration effect is prominent comparing Figure 6(d) with Figure 6(c). Figure 7 shows an example of quantitative analysis of the volume image whose size is 256×256×124×16bit, and spacing is 0.86mm×0.86mm×1.7mm. We use 3D line, angle, and reslice plane widgets to perform interactive 3D measurement of the position and size of the tumour in the brain. The measurement results are shown in the illustrations.[2]

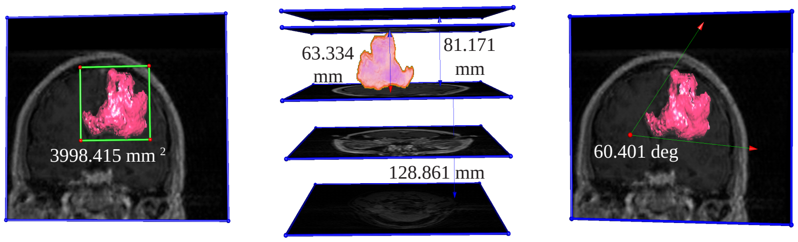
Aforementioned instances demonstrate some features of MITK and 3DMed, which can be used for surgery programming, real-time navigation, and therapy evaluation. Hereinafter, we introduce an interactive freehand three-dimensional ultrasound prototype system that is a typical computer assisted intervention system developed with MITK and 3DMed. The hardware structure of the freehand system is shown in Figure 8(a). We use a WEUT-70X ultrasound scanner with a 3.5 MHz curved-array probe for image acquisition. Output videos of the scanner are captured and digitized into discrete 2D images by a video frame grabber (OK_M10A). An electromagnetic position sensor (FASTRAK) is used to track the six degree-of-freedom parameters of the probe. The PC is the core of the hardware, which hosts the interactive freehand 3D ultra-

[2]The original data of Figure 4(b) is from http://www.psychology.nottingham.ac.uk/staff/cr1/ct.zip; the original data of Figure 6 is from http://www.bic.mni.mcgill.ca/brainweb; the original data of Figure 5 and Figure 7 is from Beijing Shougang Hospital.



(a) (b) (c) (d)

Figure 6: Registration of two volume images. (a) The reference image; (b) The moving image; (c) The fusion image before registration; (d) The fusion image after registration.



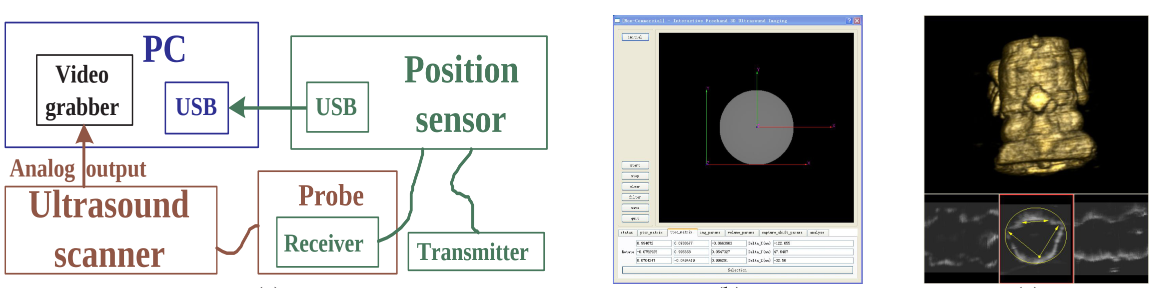
(a) (b) (c)

Figure 7: Measurement of the tumor. (a) area measure based on surface rendering; (b) distance measure based on volume rendering; (c) angle measure based on surface rendering.

sound software system. The software system consists of an imaging platform and the 3DMed. The imaging platform shown in Figure 8(b) is used for obtaining 3D ultrasound images, while 3DMed is used for post processing and analyzing. The imaging platform uses MITK to implement the reconstruction and display modules, and employs QT to design the GUI. An interactive freehand technique [2] is used to integrate the acquisition, reconstruction, and display modules together into the user interface, which enables the platform to generate high quality images. We place a plastic elephant in a water bath, and utilize the imaging platform to perform 3D ultrasound reconstruction of the phantom interactively. Figure 8(c) shows the post processing results of the reconstructed volume image on 3DMed. Besides the described freehand system, an ultrasound image guided tumor melting system is being developed by us, where MITK and 3DMed is used for 3D ultrasound imaging, surgery programming, and navigation. These applications demonstrate that MITK and 3DMed can be used for developing practical computer assisted intervention systems.

6 Conclusions

An integrated medical image processing and analyzing software platform, MITK & 3DMed, is introduced in the present paper. The platform is not yet open source, however it is open interface, the library of MITK and



(a) (b) (c)

Figure 8: Interactive freehand 3D ultrasound system. (a) The hardware structure; (b) The imaging platform; (c) Processing and analyzing with 3DMed.

executable program of 3DMed can be downloaded and used freely. Recently we have released MITK 1.4 Linux version and 3DMed 2.1 Windows version at http://www.mitk.net. MITK and 3DMed have exceeded 10500 downloads till now. Users consist of researchers, clinicians, engineers and so on. The real-time download statistics can be found from http://www.mitk.net/downstat.php. We have constructed a forum for MITK and 3DMed at http://www.mitk.net/forum. The total number of register members has exceeded 5500. Large amount and scope of uses fully testify the validity and flexibility of the platform. Besides being used for teaching and scientific research, MITK and 3DMed also for clinical applications such as assistant diagnosis of retinal disease and interactive segmentation of nerve tissue. Moreover, practical computer assisted intervention systems such as interactive freehand three-dimensional ultrasound imaging system and ultrasound image guided tumor melting system can be developed based on MITK and 3DMed. These application cases well show the applicability of this platform for the development of computer assisted intervention systems.

7 Acknowledgements

This work is supported by NBRPC (2006CB705700), PCSIRT (IRT0645), CAS HTP, CAS SREDP (YZ0642,YZ200766), 863 Program (2006AA04Z216), JRFOCYS (30528027), NSFC (30672690, 30600151, 30500131 and 60532050), BNSF (4071003) in China.

References

[1] Analyze. AnalyzeDirect, http://www.analyzedirect.com/Analyze/. 1

[2] Yakang Dai, Jie Tian, Jian Xue, and Jiangang Liu. A qualitative and quantitative interaction technique for freehand 3d ultrasound imaging. In *Proceedings of EMBS'06*, pages 2750–2753, New York, USA, 2006. IEEE Engineering in Medicine and Biology Society. 5

[3] L. Ibanez, W. Schroeder, L. Ng, and J. Cates. *The ITK Software Guide*. Kitware, Inc. ISBN 1-930934-15-7, http://www.itk.org/ItkSoftwareGuide.pdf, second edition, 2005. 1

[4] QT. Trolltech, http://www.trolltech.com. 4

[5] W. Schroeder, K. Martin, and B. Lorensen. *The Visualization Toolkit: An Object Oriented Approach to 3D Graphics 4th Edition*. Kitware Inc, 2006. 1

[6] IGT: Toolkit. Brigham and Women's Hospital, http://wiki.na-mic.org/Wiki/index.php/IGT:ToolKit. 1

[7] J. Udupa, R. Goncalves, K. Iyer, S. Narendula, D. Odhner, S. Samarasekera, , and S. Sharma. 3DVIEWNIX: An open, transportable software system for the visualization and analysis of multidimensional, multimodality, multiparemetric images. In *Proceedings of SPIE*, volume 1897, pages 47–58, 1993. 1

[8] VolView. Kitware, http://www.kitware.com/products/volview.html. 1

[9] I. Wolf, M. Vetter, I. Wegner, T. Bottger, M. Nolden, M. Schobinger, M. Hastenteufel, T. Kunert, and H. Meinzer. The medical imaging interaction toolkit. *Medical Image Analysis*, 9:594–604, 2005. 1