DEVELOPMENT OF A RESEARCH INTERFACE FOR IMAGE GUIDED INTERVENTION: INITIAL APPLICATION TO EPILEPSY NEUROSURGERY


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ABSTRACT

This paper describes the development and application of methods to integrate research image analysis methods and software with a commercial image guided surgery navigation system (the BrainLAB VectorVision Cranial System.) The integration was achieved using a custom designed client/server architecture termed VectorVision Link (VV Link) which extends functionality from the Visualization Toolkit. VV Link enables bi-directional data transfer such as image data sets, visualizations and tool positions in real time. The system was tested in both laboratory experiments and in real epilepsy neurosurgeries with highly promising results.

1. INTRODUCTION

The combination of research in image analysis and image guided surgery yields a complex web of problems. In particular there are the often incompatible paired objectives of, on the one hand stability and reliability and on the other flexibility and adaptability. The second set of criteria arises from the need to test and employ cutting edge methods such as brain shift compensation and newly developed functional measurements in the operating environment, long before such functionality is available in commercial image guided navigation systems.

This is especially needed in our particular domain of application which is epilepsy neurosurgery which utilizes cutting edge research measurements such as Magnetic Resonance Spectroscopic imaging of N-acetyl aspartate (NAA) and Glutamate, spike-related fMRI maps of motor and language function, nuclear imaging based measurements of metabolism and blood flow, as well as intracranial electrode locations need to be integrated into the operating environment to help guide both electrode placement and resection.

While the development of custom image guided navigation systems is possible and has been done at some universities (e.g. [1, 2]), our approach has been to design a unique client/server link that enables research software to communicate with a commercial off-the-shelf image guided navigation system in this case the BrainLAB VectorVision (VV) Cranial system. This link was named VectorVision Link (VV Link) and is now part of the commercially available VV Cranial product line from BrainLAB. VV Link had its inception as a thesis project [3] jointly performed between Yale University, BrainLAB AG, and the Technical University of Munich. In this paper we describe the philosophy behind the design of VV Link and its first applications in epilepsy neurosurgery.

2. METHODS

2.1. Design Philosophy

The need to integrate research software such as the Yale BioImage Suite system [4] and the VV Cranial image-guided system led to a design exercise which identified the following key criteria:

1. Stability of the IGS system. In neurosurgery, failure of the equipment used by surgeons might in the worst case have lethal consequences for the patient. Hence IGS systems have extreme reliability requirements which require extensive testing. "Research quality" code, especially in early stages of development, cannot comply with those high stability premises. Thus any integration has to guarantee that the potentially faulty behavior of research code does not have any impact on the stability of the IGS system.

2. Simplicity of use. The integration needs to be targeted at developers who are interested primarily in research rather than in reading protocol or interface specifications. It is very important to make the access to the intra-operative data as easy as possible. Researchers are usually not experts in low level programming, and the goal is to enable them to concentrate on the solution of questions specific to their research project by designing an intuitively structured Application Program Interface (API). Another part of this aim is to require as
few changes as possible to their programming environment.

A number of possible solutions were envisioned namely have the research code be executed (a) in a sub-thread of the Image Guided Surgery (IGS) system, (b) as a separate process of the same system and (c) external code residing on a separate computer and communicating with the IGS system over a network connection. While choices (a) and (b) were potentially simpler, option (c) was chosen to precisely ensure the stability of the IGS system, and avoid a system crash caused by research code. The execution of research code and commercial code on separate machines also provided flexibility in the choice of operating systems (e.g. in our case Windows for VV Cranial, and Linux for the research code).

Our selected scenario (c) could have suffered from speed limitations due to network communication delays. Further investigation revealed that the only large data types that have to be transferred are the patients medical images with sizes of up to 30 MB. Assuming a standard low-traffic 100 MBit Ethernet based intra-net, one of those data sets could be transferred in approximately 5-10 seconds. As there is usually no need to transfer image sets too often (only once at the beginning of the intervention for most applications and perhaps cyclically every 10 minutes for brain shift compensation) this is no severe limitation. The other important data type is the set of tracked tool coordinates with a mean size of 1 KB. Average round trip times of 1024 Byte Internet control message protocol (ICMP) control packets on the same network as above are in the order of magnitude of 1 ms. This involved latencies will be tolerable when compared to the approximate length of a time-slice of the underlying operating system scheduler of 10 ms (WinXP). Gigabit ethernet technology should reduce such delays even further.

2.2. Network Protocol Design

Given the selection of network based communication, the next design phase involved the selection of a network communication protocol. While multiple choices were investigated, including low level socket connections, ACE, CORBA etc. we choose to extend the socket layer implemented within the Visualization Toolkit[5]. VTK provides a mechanism to distribute several well-defined independent data processing tasks to several computers in a network. This can enormously speed up the complete system if many data processing steps have to be carried through in parallel but even if the steps have to be performed sequentially, one can achieve a certain speed increase. Part of the rationale for selecting VTK as a basis was its relative popularity within image analysis research groups (including the Yale group), the availability of high quality documentation for it as well as its multi-platform nature.

Extensions to the VTK socket layer were implemented to enable the transfer of the necessary information from the VV Cranial system to a client. A client library was designed to enable the connection system. In particular the final protocol can transfer images, labeled points and tracked tool positions out of the VV Cranial system and send streaming bitmaps for display within the VV Cranial display. In addition the system also provides the necessary transformations for mapping tool coordinates and labeled points to image space. A schematic of the protocol is given in figure 1. The VV Link API at the client level consists of a small number of simple procedure calls as shown in figure 2. Implementing a sample client to enable our BioImage Suite software to communicate with VV Cranial took less than 1 day of programming time.

The final design enables the easy and robust integration of research image analysis methods into a commercial robust image guided navigation environment.

2.3. Application to Image Guided Neurosurgery

A number of functional imaging studies are routinely performed as part of epilepsy neurosurgery planning, such as fMRI, SPECT, PET and MR Spectroscopic Chemical Shift Imaging (MRSI). In addition, intra-cranial electrodes are surgically installed and subsequently localized based on post-operative MRI and CT images. Subsequently, a subset of these electrodes may represent the onset of a patient’s seizures, while another the location of speech arrest during cortical stimulation, while another represents the face recognition area discovered via event related potential (ERP) recordings. All of this data needs to be integrated into one display interface for intraoperative navigation in order to allow for the safe resection or alteration of abnormal tissue while sparing areas of critical function. While the anatomical data can be directly imported into the commercial VV Cranial system, the more research oriented images (such as MRSI, and fMRI), as well as the localizations of intra-cranial electrodes cannot be easily imported into VV Cranial (or similar systems). Part of the rationale for VV Link was to precisely enable the integration of such information into the surgical environment through the VV Link interface. Prior to such integration, the images need to be registered to the preoperative MR image used as a reference. An example of such a registration set (using methods
1. Establish Connection and Get List of Images in IGS. (SliceSet= Image)

   ```cpp
   void connectTo (std::string &host, std::string &password, int port)
   void disconnect ();
   void getSliceSetIds (< std::string > &ids)
   ```

2. Request Information from IGS, particularly stored images, labeled points and tool positions

   ```cpp
   void getSliceSet (const std::string &id, vtkImageData *image, std::string &pat_name, std::string &set_modality, unsigned char &scan_day, unsigned char &scan_month, unsigned short &scan_year, vtkMatrix4x4 *vtk_vvc_trafo, vtkLookupTable *lookup_table)
   void getLabeledPoints (vtkPolyData *points, std::list< std::string > *labels=0)
   void getTrackedTools (vtkPolyData *instruments, std::list< std::pair< unsigned int, std::string > > *time_ids)
   ```

3. Send Information to the IGS in the form of an image stream – an example is shown in the top left panel of Figure 4.

   ```cpp
   void setInfoView (vtkImageData *bitmap, unsigned char channel)
   ```

![Fig. 2. VV Link Client Application Programming Interface (as implemented in a class called VVLProxy). Note the short and concise number of calls. A few additional calls exist to enable debugging etc., but the ones mentioned above are sufficient to exploit the full functionality of the system.]

   A separate tool was also written (not shown) to enable the rapid overlaying of any type of functional data onto anatomical data in an image defined coordinate space. The whole software setup is implemented within the BioImage Suite software package. BioImage Suite is an integrated image analysis software suite developed at Yale. It uses a combination of C++ and Tcl in the same fashion as that pioneered by the Visualization Toolkit (VTK) and it leverages both VTK and the Insight Toolkit[7]. It has extensive capabilities for both neuro/cardiac and abdominal image analysis and state of the art visualization. It is currently in use at Yale; a first public test release is expected before the end of 2005.

### 3. OPERATING ROOM TESTING

The system was tested in the operating room in two surgeries so far. The first was a stage I epilepsy surgery which involved the insertion of intracranial electrodes. The system was used to visualize SPECT blood flow information within the operating room and to specifically target these regions with electrodes using intraoperative navigation. The second case was a surgical resection for epilepsy in which the full battery of fMRI, SPECT, MRSI and 3D electrode localizations was made available to the surgeons within the Image Guided surgery environment. This was the first time they could navigate in real time with such integrated multimodality data simultaneously displayed on the typical high resolution anatomical imaging. An example snapshot acquired from this second surgery is shown in figure 4.

### 4. CONCLUSIONS AND FUTURE WORK

In this paper we describe the first demonstration of the integration of research methods and a commercial off the shelf image guided navigation system (BrainLAB VectorVision Cranial). The design is generic and could be applicable in other situations, such as the integration of image acquisition systems and research software. This type of interface enables research groups to integrate more cutting edge functionality into surgical procedures while leveraging commercial, tested, stable, image guided neurosurgery systems.

### 5. REFERENCES


[3] Markus Neff, “Design and implementation of an interface facilitating data exchange between an igs system and external image processing software,” M.S. thesis, Technical University of Munich, 2003. This project was jointly performed at BrainLAB AG (Munich, Germany) and Yale University (New Haven, CT U.S.A).


Fig. 3. Applications of rigid and non-rigid registration in neurosurgical planning. Rigid and non-rigid registrations as applied for epilepsy neurosurgical planning. Here we demonstrate mapping nuclear images (SPECT), pre and post electrode implantation MR images, post electrode implantation CT images, and small-coverage MR images acquired together with MRSI measurements to the same coordinate space. To demonstrate the quality of the registration, the skull surface (shown in yellow) was extracted from the preoperative MR image (top corner) and projected to the other images using the computed registrations. Not shown, due to lack of space, is the case of fMRI activation mapping to the preoperative image.

Fig. 4. Screenshot obtained from the BrainLAB VectorVision Cranial Software during an actual neurosurgery. The top right, and the two bottom views show standard VV Cranial visualizations and tool tracking. The top left visualization shows labeled intracranial electrode location visualizations generated by the Yale BioImage Suite software and streamed into VV Cranial using the VV Link interface. The surgical pointer tool is shown as a red cone in this view. Its coordinates are also sent from VV Cranial to BioImage Suite via the VV Link interface. The screenshot was edited to hide patient identifying information.