Managing the Complexity of the User Interface of a MRI Guided Surgery System

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Abstract. Magnetic resonance imaging (MRI) guided procedures is an emerging field of image guided surgery (IGS). Interventional radiologists have specialised in image guided procedures that require the most intensive usage of imaging, therefore interactivity of the system is an important issue.

Often slow image update rate of MRI is seen as a major reason for the system latency. The development of new faster imaging sequences does not provide the desired speedup, since significant latency is introduced by the user interaction mechanisms of the current systems.

Our challenge was to design a user interface that enables the radiologists to control the system without compromising the power of MRI. This paper presents an analysis of the application and describes the user centered design and implementation of the system.

1. Introduction

Image guided surgery (IGS) is a modern approach for combining medical imaging and computer technology into a system for surgery planning and navigation [Taylor 96, Adams 90, Grimson 99]. During the recent decade, IGS technology has been applied in several fields of medicine e.g. orthopaedics [Taylor 90], neurosurgery [Galloway 92, Kosugi 88], plastic surgery, ENT surgery [Mösger 93] and interventional radiology.

The most popular IGS approach relies on the usage of preoperatively taken image data in surgical navigation. Typically computed tomography (CT) or magnetic resonance (MR) images are taken prior to surgery. The images are first used for making medical diagnosis and planning the operation. The preoperative images are registered to the patient coordinate system in the beginning of the surgery. The position of the surgical instrument is tracked and displayed on the preoperative images enabling the surgeon to accurately navigate into the target.

Preoperative images provide only static data for the intraoperative navigation. Tissue movements and deformation caused by the surgery cannot be seen in the preoperative images. Therefore, several medical imaging modalities have been used intraoperatively for providing visualisation of the dynamic effects during the surgery. The following imaging modalities are used in interventional radiology.

- Ultrasound provides real-time imaging, but its tissue differentiation capability is limited. Moreover, it cannot visualise tissues that are behind bones or air filled cavities.
- X-ray fluoroscopy provides projection images in real-time. However, the x-ray exposure of the patient and the personnel limits the amount of imaging that can be used in an operation. The soft tissue differentiation capability of the fluoroscopy is poor.
- Computed tomography supports true cross sectional 3D imaging at nearly interactive update rate. The drawbacks are the usage of x-rays and limited scan plan orientations.

Magnetic resonance imaging (MRI) is a superior diagnostic medical imaging modality due to excellent tissue characterisation and its capability for true 3D imaging without x-ray radiation. The possibility of selecting the scan plane direction arbitrarily is a remarkable advantage in imaging guidance.

MRI environment is a difficult operating environment due to strong magnetic field and strict electromagnetic compatibility (EMC) requirements. Moreover, MRI is not a real-time imaging modality. The imaging time is highly dependent on the desired image quality, but it normally varies from several hundred milliseconds to a few minutes. The potential of MRI in intraoperative imaging is generally agreed on, thus technology is being developed to overcome the recognised difficulties.

This paper describes the study and development of a user interface for a MR guided surgery system targeted to radiological interventions. Radiologists are professionals who use medical imaging for diagnosing anatomical and functional pathologies. However, the development of the image guidance technology has altered the traditional boundaries between the fields of medicine. Nowadays image guided operations are done both by imaging specialist i.e. radiologists and treatment specialists i.e. surgeons.

2. Current systems

All global MRI scanner manufacturers have brought open magnet configurations to the market. These new generation magnets provide access of the patient during image acquisition enabling the development of MR guided procedures [Alexander 96, Jolesz 98].

Almost all manufacturers of open magnets have developed systems for the MRI guided procedures. These systems have essentially the same principle components; a scanner, a display, an optical navigator [Adams 96] and a user interface console. The components of a MR guided surgery system are presented in Figure 1.

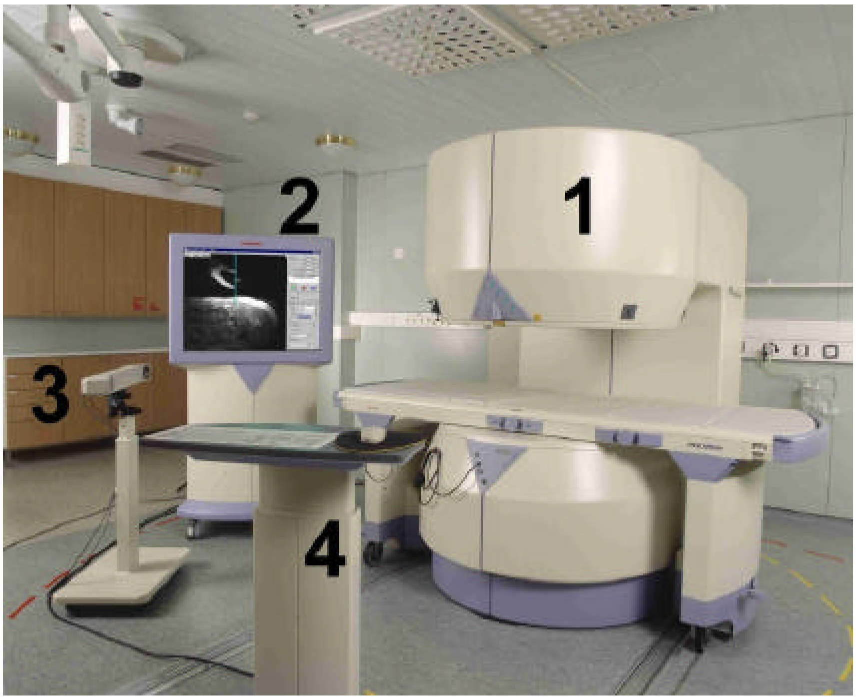

Figure 1. The primary components of the current MR guided procedure system are 1) open configuration MR scanner, 2) display, 3) optical navigator, and 4) user interface console.

All the current systems are controlled with software that is modified from the software originally developed for diagnostic imaging. The user interface of the available software systems is implemented by using the standard mouse driven graphical user interface (GUI) approach. During an operation, the surgeon gives verbal commands to a technician who operates the system via the GUI.

The collaboration of the surgeon and the technician requires training and agreed terminology before the interaction is possible. Our experience gained from over 100 procedures performed with a current state-of-the-art MRI guided surgery system demonstrates that verbal communication is problematic even for experienced teams. Giving clear and exact verbal instructions is often difficult for a doctor while he is concentrated on performing an operation. Giving unambiguous instructions that include attributes such as amounts, measures or directions is considered especially difficult. In addition, image acquisition of the MRI scanner produces a significant amount of noise, which disturbs the verbal communication.

Synchronisation of the surgeon's instructions and consequent actions performed by the technician is also critical for success of an operation. The completion of the control tasks performed on the current systems takes a variable amount of time. The surgeon cannot normally follow the progress of the control actions, thus he is not able to synchronise his verbal instructions to the control resulting in missed commands. Training of the team improves the synchronisation, but it is never likely to eliminate the problem.

3. Application analysis

MRI provides large amount of imaging parameters that can be adjusted when tissue contrast, signal to noise ratio, resolution or imaging time is optimised for a specific purpose. The required imaging properties are often in contradiction, thus a vast amount of MR sequences with adjustable parameters have been developed for diagnostic imaging.

The possibility to optimise tissue characterisation is required during diagnostic imaging, since at that time it is not exactly known how the abnormality should be imaged. However, the situation is different in the intervention, since the target has been found in the diagnosis and thus the means for visualising it are known. This knowledge can be used to reduce the amount of imaging sequences and adjustable imaging parameters in the interventional use.

The complexity of the user interface increases when the MRI system is combined with an IGS system. The software should provide possibility to e.g. calibrate instruments, to select between different visualisation modes, overlay graphics, and navigation modes.

Imaging is intensively used during the operations for instrument guidance and monitoring the therapeutic or diagnostic actions performed. Direct control of the MRI system is considered to be a necessity for the radiological image guided procedures, since the surgeon needs to control the functionality of the imaging system frequently.

The time used for the control actions is another important criterion, since fast system response is required in the operations that should be performed within a short time frame defined by physiological or practical constraints. An example of such an operation is needle biopsy of liver within a breath hold period.

Secondly, the feasibility of a treatment is defined not only by its clinical excellence but also by the operation costs. MR guided procedures can be promoted with excellent image quality and lack of ionising radiation. However, the time used for operations should be decreased before the same patient throughput can be achieved than with other modalities. The direct system control is expected to improve the interactivity and thus decrease the operation time.

4. Design metaphor

We recognised that driving a car is a real world metaphor for our problem. The main task during driving is to monitor the traffic and steer the car in a dynamically changing environment. The controls of a car have been designed to enable full control without moving the eyes from the surrounding traffic. The gauges of the car are designed to be clear and thus instantly observable. We used the metaphor through the design phase to check the proposed solutions.

5. System components

We have developed a research software platform under the Linux (2.2.x) operating system for studying instrument tracking, visualisation and user interaction technologies for MR guided procedures. The system is connected to an open configuration MRI scanner via a networking protocol, which enables MR image requesting and reception with minimum latency. We implemented the designed user interface concepts into the research software.

A special MR compatible user interface console, presented in Figure 2, was designed for the system. The console consists of a panel integrating a joystick with three buttons in the handle, 3x2 matrix of large buttons, four small buttons and two spin discs. Two foot pedals, used for triggering MR scanning, were connected to the system.

We applied a set of human computer interaction patterns [Tidwell 99] in our design. The system components and patterns applied are presented in the following paragraphs.

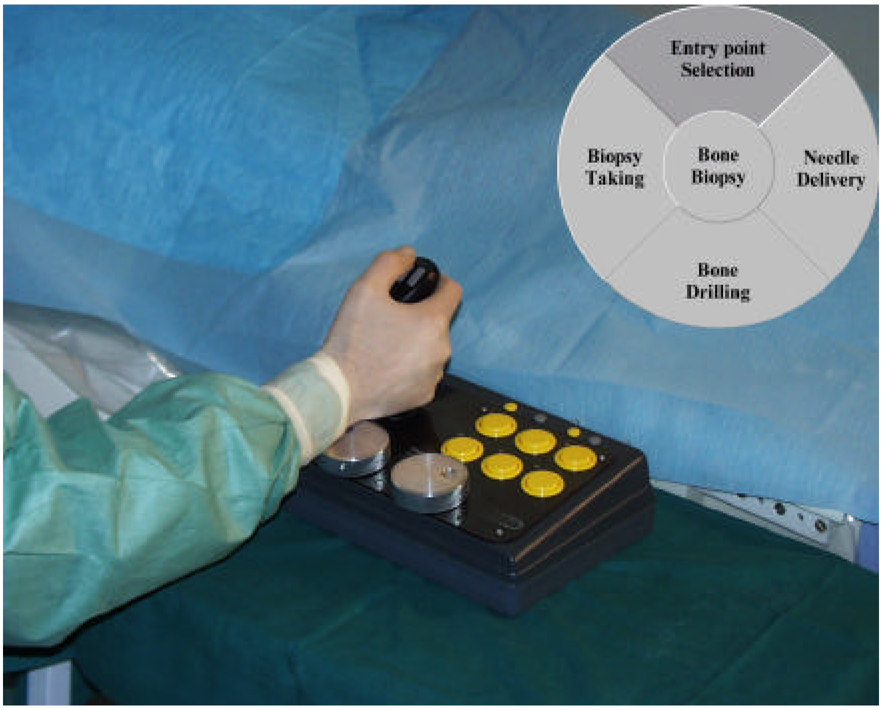

Figure 2. The user interface console developed for the system. The joystick is used to make menu selections from the pie menus.

5.1. Workspaces

The first attempt to simplify the complexity was to find sub-problems of manageable size. An image-guided surgery procedure consists of different phases e.g. entry, point definition, instrument delivery, and therapeutic action. The requirements are manageable, if the individual phases are considered. We decided to create a possibility to define a set of workspaces for each surgical procedure. Single workspace will be used in one phase of operation and the workspaces could be navigated according to the progress of the operation.

Physically our minimum workspace consists of the predefined views, layout of the views, set of overlay graphics, and a set of imaging sequences. The views are either 2-D or 3-D visualisations from the preoperative or intraoperative image data. In addition to visualisation technique, the direction of the view with respect to an instrument is predefined. Currently we use over ten different view directions in visualisation.

The layout of the views is typically a regular 2x2 or 3x2 array of the visualised images. Figure 3 shows an example workspace with a 2x2 layout consisting of visualisations from preoperative and intraoperative image data.

The overlay graphics consists of the graphical presentation of the instrument, rulers and text. The body of the instrument, the location of the tip and the extension of the instrument are presented on top of the MR images. Centimetre scaled rulers are drawn on the sides of the image. The user selectable imaging parameters are shown on top of the image.

A *map of navigable workspaces* is implemented by using a pie menu [Callahan 88]. Pressing a button of the joystick enables the workspace pie menu and pushing the joystick to the direction of the desired menu item does the selection. An example workspace pie menu developed for bone biopsy is shown in Figure 2.

The major directions of the joystick can be used to select the menu items, if the available items are restricted to eight. This solution originates from the metaphor of the manual gearbox of a car and it enables making selections without watching the screen.

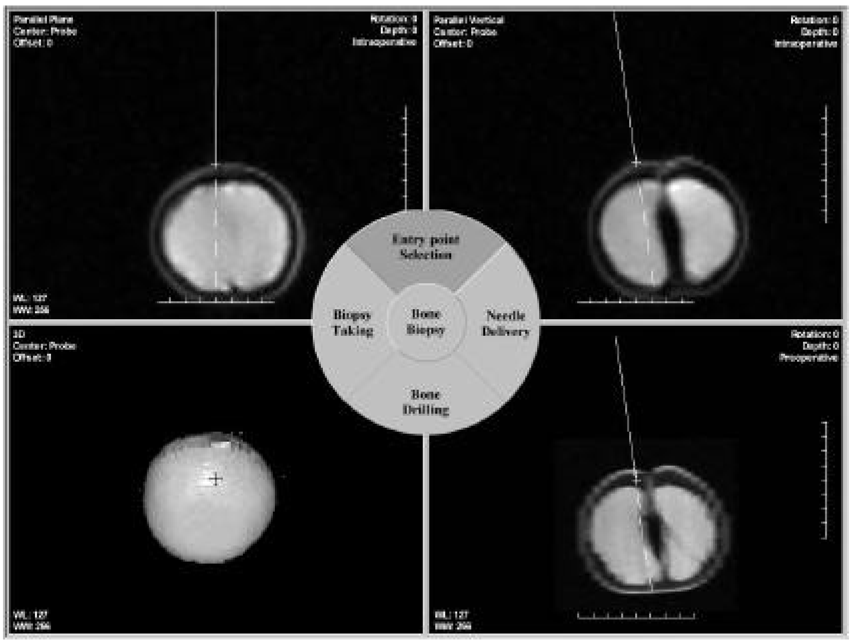

Figure 3. An example workspace demonstrating a 2x2 image layout. Workspace selection pie menu has been popped on top of the workspace views.

5.2. Default values and preferences

We were able to apply more simplifying patterns after separating the operation phases into the individual workspaces. There is only a small set of imaging sequences and other parameters that should be available in a single phase of an operation. This enabled us to define *good defaults* for the parameters. As a result we got a small set of imaging sequences per workspace enabling us to use pie menu to make selections.

We decided to provide a mechanism for the user to define the *preferred values* of the parameters. Simple human interpretable configuration file was provided for setting the defaults and user preferences for the system. The configuration file defines entirely the workspaces, imaging sequences used and a set of other possible parameters. In principle, one configuration file can be generated for each different kind of clinical procedure.

5.3. Improving interactivity

We also applied several patterns for improving the interactivity. Since there are always several images at the same time on the screen, it is natural that *multiple objects are manipulated* at once.

We used the 3x2 matrix of the large buttons for addressing the individual views of the workspace. Several views can be rapidly selected for manipulation by pressing the corresponding buttons. The spin discs are used to manipulate the views. The provided operations are image resizing, contrast adjusting, view direction rotation around the instrument axis and virtual instrument pushing. The mode of manipulation is selected with the small buttons of the controller.

We also used a *remembered state* pattern. The adjustable parameters are recalled when the user returns to a workspace where he has been before. The parameters are always remembered within a workspace although the imaging sequences or visualisation modes are changed.

Our implementation follows *repeated framework*s pattern as much as it was considered feasible. The usage of workspaces allows defining unique behaviour, set of defaults and user interface for each phase of an operation. All the mentioned properties are sometimes desired, but in order to ensure smooth mental transition of the user between the workspaces, the behaviour and user interface of the workspaces were restricted to be as equivalent as possible.

6. Fantom experiments

We have not yet brought our MR guided procedure system into clinical evaluation phase, thus we evaluated the concepts with fantom experiments where grapefruit has been used as a target instead of a patient. The fantom experiments do not provide reliable means for measuring the improvement of interactivity of the system, since in reality there are almost always structures, which should be avoided, between the skin entry point and the target lesion. Therefore, need for imaging and using the system for guidance is more intensive in real cases affecting the measurements significantly. We target to bring the system into the real clinical trials in order to obtain the desired data.

However, we were able to verify two properties with the fantom experiments. First, the learning curve of the system was evaluated. Second, the radiologist's ability to perform a biopsy by directly controlling the system was studied.

We selected two interventional radiologists having prior MRI experience, but no knowledge of our system. The first radiologist was a senior having several years experience in performing interventions with other imaging modalities. The second one was a resident in radiology, who has gone through the intervention training.

We first briefly introduced the functionality of the system and then guided them through an example biopsy operation. Thereafter they were let to perform an operation without guidance. We found out that both of the radiologists were able to learn the functionality of the system in less than 30 minutes. They were also able to control the system by themselves during the simulated procedure. After the training period they were capable to change workspaces and select imaging sequences without looking at the display.

7. Conclusion

We were able to develop a concept for managing the complexity of the user interface of a system intended for performing MRI guided radiological procedures. The fantom experiments showed that the concept is feasible in practise.

We intend to bring the system into the clinical testing in the future. Moreover, we consider that our approach for structuring and simplifying the user interface allows us to apply voice recognition in a command and control manner. Practical voice recognition approach could allow the interventionist to perform simple actions while his both hands are allocated into the operation.

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