C. Martin Reich*, Michael Unger, Leon Melzer, Thies Jochimsen, Bernhard Sattler, Osama Sabri, Andreas Melzer

Developing an Intuitive and Feasible Setup for In-room Control During MRI-guided Interventions

Abstract: Magnetic resonance image (MRI)-guidance for minimally invasive interventions instead of CT-guidance is a promising technique to reduce radiation exposure for both patients and clinicians. Technical challenges have to be managed in order to meet safety regulations while enabling in-room system control and communication. Using non-proprietary software and hardware, several gradations for a setup for interventional MRI were elaborated. Eventually, a quickly and easily installable setup was established for technical support during MRI-guided interventions in the PET/MRI suite at the Department of Nuclear Medicine at University Hospital Leipzig. It is adaptable for most MRI suites.

Keywords: Magnetic Resonance Imaging (MRI), MRI remote control, MRI-guided interventions, Interventional MRI.

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1 Background

In recent years, many research groups have discussed and proven the advantages of interventional MRI [1]. Several feasibility studies for vascular interventions have been successfully conducted, such as right heart catheterization, endomyocardial biopsy, and coronary intervention [1, 2, 3]. However, only a few have made it to clinical routine, for example, cardiac ablation [4].

Given the fact, that most MRI sites are designed for diagnostic procedures, there is usually no preinstalled setup to support clinicians during MRI-guided interventions. That is, interventional MRI room require for patient monitoring hardware, system user interface, video display and communication system [4]. In an MRI environment, magnetic field forces and radio frequency (RF) induced heating pose threads when using electronic devices. Therefore, some manufacturers sell MR-safe labelled technology like RF-shielded monitors (*Cambridge Research Systems Ltd.*). Furthermore, MRI-system manufacturers provide software for interactive real-time imaging [5]. Purchase of these dedicated tools, however, exceed the financial resources of most clinical departments.

Our approach aims for a midway, everyday-use technology and equipment as well as no need for special trained experts to implement it. The goal is to make it feasible to a broader community, trying to adapt an exemplary interventional suite to the MRI environment.

2 Exploring the Environment

At first, the PET/MRI site at the Department of Nuclear Medicine at University Hospital Leipzig was examined. Suitable locations for the technical equipment had to be identified for use next to the gantry bore. The following aspects were taken into account:

1. free space in/on built-in furniture
2. Location of waveguides
3. Access to mains supplies
4. Walking routes

Roughly structuring the approach as a whole, we focused on three more or less independent sub-issues: system control, communication, and video playback. This paper focuses primarily on the aspects of operating the PET/MRI-system. Therefore, it avoids dealing with patient involvement as this would complicate the procedure and impose ethical issues, respectively.

***Corresponding author: C. Martin Reich:** Innovation Center Computer Assisted Surgery, Universität Leipzig, Semmelweisstraße 14, 04103 Leipzig, Germany, e-mail: christophmartin.reich@medizin.uni-leipzig.de
Michael Unger, Leon Melzer: Innovation Center Computer Assisted Surgery, Universität Leipzig, Germany
Thies Jochimsen, Bernhard Sattler, Osama Sabri: Department of Nuclear Medicine, University Hospital Leipzig, Germany
Andreas Melzer: Innovation Center Computer Assisted Surgery, Universität Leipzig, Germany

2.1 MRI system control

Usually, an MRI system is controlled by a technician in the control room next to the system suite only, supported by visual contact through a window and/or using a camera. Parameters can be manipulated via the software running on the dedicated system console with the standard input devices keyboard and mouse. For classical interventional use cases, such as needle guided biopsies, this might be sufficient [6, 7]. However, interventionalists usually control and monitor the imaging system while simultaneously treating the patient (i.e. cardiac catheterization). Consequently, the MRI system's in- and output devices need to be routed into the MRI room. An optical USB extension cable (*OPTICIS CO., LTD.*) was installed to pass the faraday cage's wall via waveguide. Next, several off-the-shelf wireless mice were tested regarding their behaviour inside the MRI-room to minimize undesired attraction when used beyond the 5 Gauss line. To do so, the devices were exposed to a common neodyme magnet N45. Most built-in batteries should be removed and replaced with rechargeable lithium polymer batteries that are non-ferromagnetic. The same conditions apply for other human interface devices (HID), even wired models when used at a safe distance to the system. Some devices may trigger a warning that the system has been compromised after plugging into the USB port of the console workstation and possibly limit its functionality. To avoid this, only devices running on the systems' HID driver shall be used.

2.2 Communication

Communication within the clinical team is impacting the efficiency as well as the safety of the procedure. Hence, using hand signs or walking in and out to communicate with the technician is not very suitable and error-prone. The Use of the PET/MRI built-in microphone and speaker systems is limited due to the position of the microphone at the gantry. The most sophisticated and MR-Safe communication system uses infrared transmission [*Optoacoustics LTD.*]. So far, the procurement and installation of this system are expensive and time-consuming. Recent mobile audio technology, though, brought true wireless noise-cancelling for in-ear headsets on the market. Such devices can easily be worn underneath over-ear noise protectors. Again, trial and error is the only way to provide the necessary information for their behaviour in the static magnetic field. The mandatory noise protectors, provide additional protection from loosening headphones falling out and being attracted by the static magnetic field. The headsets were Bluetooth paired to a mobile device, which itself was connected to a local VoIP (Voice over Internet Protocol) server on a laptop in the control room. For this purpose, we set up a wireless local network in the MRI room with a standard router. The connection between router and laptop was realised by using media converters (*Allied Telesis International GmbH*) in order to pass the waveguide via fibre optic duplex patch cables (*LINDY-Elektronik GmbH)*.

2.3 Video Playback

Essential for interventional procedures is the live monitoring of the treatment. Therefore, the video signal of the MRI-console was routed via optical fibre cables and adapters (*LINDY-Elektronik GmbH*) through the waveguide to a monitor in the scanner room. Monitors can be mounted onto the inner wall at an adequate distance to the bore. The disadvantage of this approach is the limited positioning possibilities. Also, it could be attached to a mobile MR Safe rack. By using a projector and a $2m^2$-screen, it is possible to avoid putting electronic devices too close by the gantry allowing more flexibility for the devices' location. Additionally, the size of the projection allows for sufficient visibility for the whole team.

3 Implementation

After having elaborated the technical possibilities, they were combined to build an integrated setup. The MRI premises necessarily provided the framework for that. Step by step, multiple options were elaborated: starting out with a low budget and low effort – must-have – approach and further evolving it systematically to a more sophisticated – nice-to-have – solution.

3.1 Minimal Requirements

To successfully operate the system from inside the PET/MRI room, one input and one output device are needed at least. The starting point was the equipment already in place. As input served a wireless mouse (*Targus Corporation*) with an alloy case and modified battery pack (as described in section 2.1). Even when a scan is in progress, this mouse is working normally. Attraction by the static magnetic field started in a distance to the bore of about 50cm. Using it at the foot end of the patient table was possible without any problem. Importantly, the standard mouse stayed plugged in providing full control by a technician in the control room as before. A wall-mounted 19-inch LCD monitor (*NEC Display Solutions Europe GmbH*) showed a duplicate of the video signal (tapped with a DVI-splitter) of the console workstation. Power supply inside the PET/MRI room was managed via the shielded power socket near to the waveguide to the control room. All cables were placed on the floor alongside the skirting.

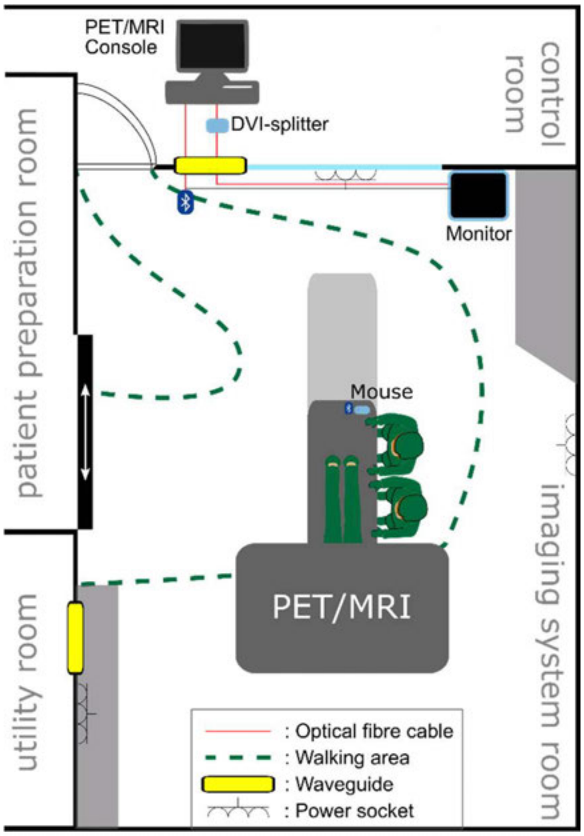

Figure 1: Schematic floor plan of the PET-MRI at the Department of Nuclear Medicine at the University Hospital Leipzig (not in scale). Cupboards and shelfs depicted in gray in the lower left and upper right corner. Patient entry is possible via preparation or control room.

3.2 Advanced Setup

To offer clinicians best possible technical support during a PET/MRI-guided intervention, an advanced setup was established. In catheter laboratories, there are multiple displays above the patient table, showing fluoroscopy images and physiological parameters.

We decided to use a projector (*NEC Display Solutions Europe GmbH*) and a roll screen (case and wind made of alloy - *celexon Europe GmbH*). This approach allows more flexibility of installations in the imaging systems room. Both were attached to panels of the suspended ceiling. Even though the rolled-out canvas blocks the exit through the sliding door into the preparation room, there is still the exit through the control room. Given the position of the participating clinical personnel, the projections trajectory is not disturbed. All cables were hidden in cable ducts or the ventilation system beneath the ceiling to prevent tripping hazards.

A wired foot pedal (*dr. dresing & pehl GmbH*) was added as an input device, increasing usability and comfort. In a classic interventional suite, a pedal is used to start/stop fluoroscopy. We used a programmable device, opening up more opportunities such as to start/stop scanning or to scroll through tomographic slices.

Communication was realized with *AirPods,* an *iPad Air 2* (*Apple Inc.*), a *Fritzbox* router (*AVM GmbH*), and an open-source VoIP software (*mumble*). The proposed solution allows connecting as many participants on any platform as desired since it is primarily intended for online gaming. Issues with shielded microphones were overcome by modifying the noise protectors. Other headsets even have integrated bone microphones. For better utility, a headset or table microphone can be connected to the laptop in the control room.

The tablet used to connect the headset was mounted in a holder (in-house 3D-printed polylactide) attached to holes in the table for sanitary paper rolls at the foot end.

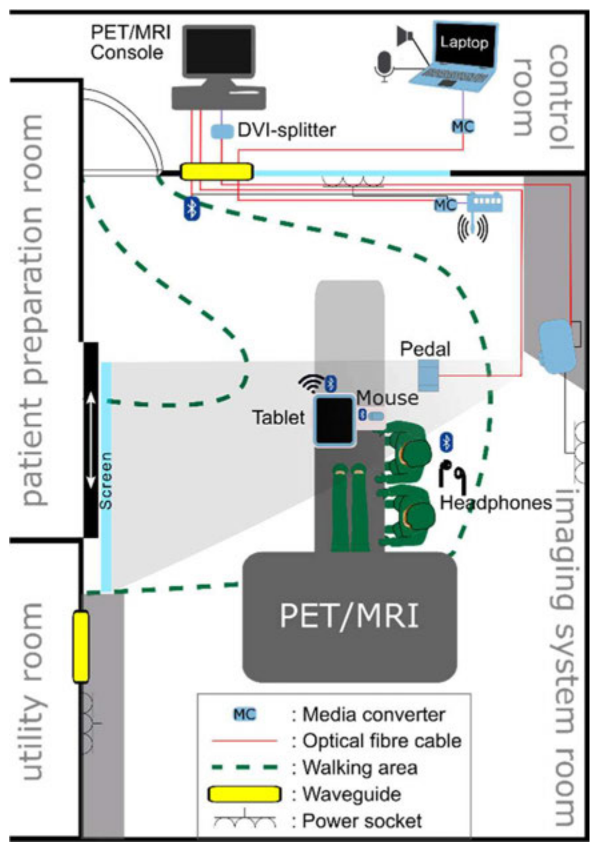

Figure 2: The advanced setup comprises multiple input devices, an output device, in-room network for VoIP and/or VNC connection. Although this scheme look overcrowded this it is actually quite comfortable in practical use.

4 Further considerations

The big downside of putting electronic devices inside the MRI room is interference and hence deterioration of the MRI signal. For diagnostic imaging, this is not acceptable. Yet, real-time imaging has a relatively low spatial resolution. Of course, the optimal scenario includes both, but most facilities do not have the required means to effort faster gradients or computational systems. To bypass this particular problem it is advisable to run diagnostic sequences with a high spatial resolution before the technical setup is online – meaning all wired connections are interrupted. Compliance with safety regulations is strongly advised before permanently establishing such a setup. Several test methods that are accepted by regulatory bodies address MR safety and compatibility issues [8]. Moreover, manufacturers provide test sequences with dedicated phantoms.

The issue of hygiene needs to be addressed as well. Sterile draping of the devices must be provided without impairment of usability. The devices as mentioned above still worked when draped and used with gloves.

Further, with VNC (virtual network computing) server-client software, it is possible to remotely control a workstation. If administrative access to the console workstation is provided this opens up even more opportunities for in-room imaging system control [9]. This feature also could be used to access patient databases and display imaging data or clinical reports from inside the imaging systems room.

Another application with a possible clinical scope is the operation of robotic systems. In a demo setup (see Figure 3) with just a few adjustments (using the other waveguide and additional media converters), we managed to in-room-control simple movements of a robotic arm (*Innomotion*, *IBSmm Engineering*).

Figure 3: Demo setup at PET/MRI (Siemens 3T). Pneumatic robotic arm with attached needle-guide over an abdominal phantom. At the foot end of the patient table are the mouse and the mounted tablet that displays the *Innomotion* control software. In the background the PET/MRI console GUI is projected on the roll screen.

As for now, the established technical setup for in-room PET/MRI system control is suitable for research. The functionality of the setup was successfully tested by performing a needle-guided biopsy in a phantom (setup as shown in Figure 3 without *Innomotion*). As every site is different, there is no blueprint for an optimal solution. For our setup, we could prove feasibility, affordability, and flexibility. Extended safety investigations while broadening the application will be conducted next. Concurrently, implementing additional devices may enable a broader range of applications to conduct research studies, for example, vascular interventional use cases. Moreover, provisions for installing such equipment could be made in the planning phase of hybrid PET/MRI imaging suites, should our approach further prove its utility in our research setting.

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