Introduction

The 2D MR image overlay system (IOS) concept is effective in a variety of musculoskeletal procedures (Figure 1) [1, 2, 3]. Because of the vertical orientation of the image plane, insertions are currently limited to the axial plane. However, for obliquely oriented anatomic targets (disc spaces, vertebral bodies, hypogastic plexus) and for biopsy targets, optimal percutaneous access often requires oblique insertion.

Figure 1. Hardware configuration (support) and software architecture (shower) of the MR-guided needle navigation system.

To allow for image-guided needle insertions in oblique planes, we have:
1. developed the “MR image overlay adjustable plane system (IOAPS)”
2. proposed an intraoperative calibration method
3. assessed the motion characteristics of the 4-DOF for intraoperative calibration and tested the encoders functionality.

Methods

System overview

The IOAPS consists of two main units (Figure 2): In-Room Unit and Out-of-Room Unit.

![Diagram of system overview](image)

Figure 2: (Left) Diagram of the IOAPS and its 6-DOFs. (Right) IOAPS coordinates system and diagram of calibration phantom with Z-shaped fiducials in each image motion (a-c) and frontal plane of the calibration phantom with MR-donut skin markers, where the laser plane cut through.

Calibration Procedures

The proposed calibration method is based on the assumption that the virtual image plane is superimposed upon the target plane.
- **Constructive Calibration:** Align the virtual image plane to coincide with the overlay transverse laser plane; this is performed during the built-up of the IOAPS device.
- **System Calibration:** Align the laser plane parallel to the scanner laser plane; this is a preoperative calibration and uses the calibration phantom (Figure 3 right) to define the home position.
- **Motion Calibration:** Calibrate system motion indicated by encoders to 2D image motion using the calibration phantom (Figure 3 right); this is an intraoperative calibration. To simplify the calibration procedures, the translation joints will be fixed at a distance and assumed motionless during the procedure.
- **Software Calibration:** The radiologist moves the virtual image plane until the real fiducial markers on the phantom and their virtual images overlap perfectly on the phantom; this is performed after acquiring MRI data from the calibration phantom.

Calibration Phantom

The triangular phantom is designed for:
- **System Calibration – Frontal plane of the phantom indicates the alignment of laser planes (Figure 3 right).**
- **Motion Calibration – Z-shaped markers show different patterns through out the hardward motions (Figure 3 right).**

![Diagram of calibration phantom](image)

Figure 3. (Left) Diagram of the IOAPS and its 6-DOFs. (Right) IOAPS coordinates system and diagram of calibration phantom with Z-shaped fiducials in each image motion (a-c) and frontal plane of the calibration phantom with MR-donut skin markers, where the laser plane cut through.

Conclusion

The IOAPS system was designed and built. A calibration method was developed and a workflow was proposed. A preliminary motion characteristic analysis was performed and the encoder functionality was assessed.

- **Preliminary data currently suggest considerable translations errors due to elastic deformation from vibration during the motion. However, those appear fixed and are thus not expected to substantially affect the system performance.**
- **The rotations around the X-axis and Y-axis are stable within the ±5 deg and ±10 deg limits, respectively.**
- **Our results support further evaluation of the IOAPS system with optical tracking, which affords assessments through real-time tracking and real-time registration.**

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References