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The Perk Station: Design of a percutaneous intervention training suite

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Abstract: Image-guided percutaneous needle-based surgery has become part of routine clinical practice in performing procedures. Image-guided needle placement procedures in CT/MR require an accurate and effective augmented reality (AR) system. In order to operate the system, the operator needs to be trained. Therefore, we have developed a laboratory validation and training system for measuring operator performance using different assistance techniques. Three techniques are fitted in this training suit: the image overlay, bi-plane laser guide, and traditional freehand techniques. Electromagnetic system is applied in the validation system. Electromagnetically tracked needles are registered with the preoperative plan to measure placement accuracy and the insertion path. The validation system provides an independent measure of accuracy that can be applied to varying methods of assistance ranging from augmented reality guidance methods to tracked navigation systems and autonomous robots. *Perk Station*, an inexpensive, simple and easily reproducible surgical navigation workstation for laboratory practice incorporating all the above mentioned functions in a "self-contained" unit is introduced.

Keywords: Percutaneous Interventions, Augmented Reality, Training

1. Introduction

In recent years, numerous surgical guidance and navigation methods have been developed for needle-based surgery. Image-guided percutaneous needle-based surgery has become part of routine clinical practice in performing procedures such as biopsies, injections and therapeutic implants. Contrary to casual observation, needle-based surgery can be an exceedingly complex intervention. Translation and rotation motions, as well as bending and insertion forces can be combined for delicate needle control in needle-based surgery. Space and the means for desired maneuvering of the surgical device, however are extremely limited. Last but not least, detecting and recovering from errors such as internal bleeding increase the risk of these otherwise appealing outpatient procedures. Trainees usually perform needle interventions under the supervision of a senior physician. This is a slow and inherently subjective training process that lacks objective, quantitative assessment of the surgical skill and performance. Current evaluations of needle-based surgery are also rather simplistic: usually only needle tip accuracy and procedure time are recorded, the latter being used as an indicator of economical feasibility. Many important nuances that pertain to collateral morbidity, side effects, pain and patient discomfort are not captured in current surgical performance evaluation methods. To address these issues, we develop the Perk Station which is an inexpensive, simple and easily reproducible surgical navigation workstation for laboratory practice with non-biohazardous specimens.

2. The Perk Station

The Perk Station comprises image overlay (Fichtinger G. et al, 2005), laser overlay (Fischer et al, 2006), and standard tracked freehand navigation in a single suite. The image overlay consists of a flat display and a half-silvered mirror mounted on a gantry as seen in Fig. 1 (left). After calibration, when the physician looks at the patient through the mirror, the CT/MR image appears to be floating inside the body with the correct size and position as if the physician had 2D ‘X-ray vision’. Prior to needle insertion the image is transferred directly in DICOM format to the planning and control software running on a stand-alone laptop where we mark the target and entry points, draw a visual guide along the trajectory of insertion, mark the depth of insertion and push this image onto the overlay display. The laser overlay uses two laser planes; one transverse plane and one oblique sagittal plane. The intersection of these two laser planes marks the needle insertion path. For convenience, a second oblique sagittal laser can be added to support bilateral interventions. In tracked navigation (Terry, P. and Kevin C., 2008), the planned needle path can be superimposed in orthogonal planes, in oblique plane including the needle, or in transparent volumes. A stand-alone laptop computer is used for image transfer, surgical plan and appropriate rendering. The actual structure of the Perk Station is shown in Fig. 1. The image overlay is mounted on one side and the laser overlay and tracked navigation system on the opposite side. The user can swap between the techniques simply by turning the system around. The extruded aluminum frame is sufficiently strong to hold the weight of all devices, yet it is still sufficiently lightweight to be portable in a suitcase.

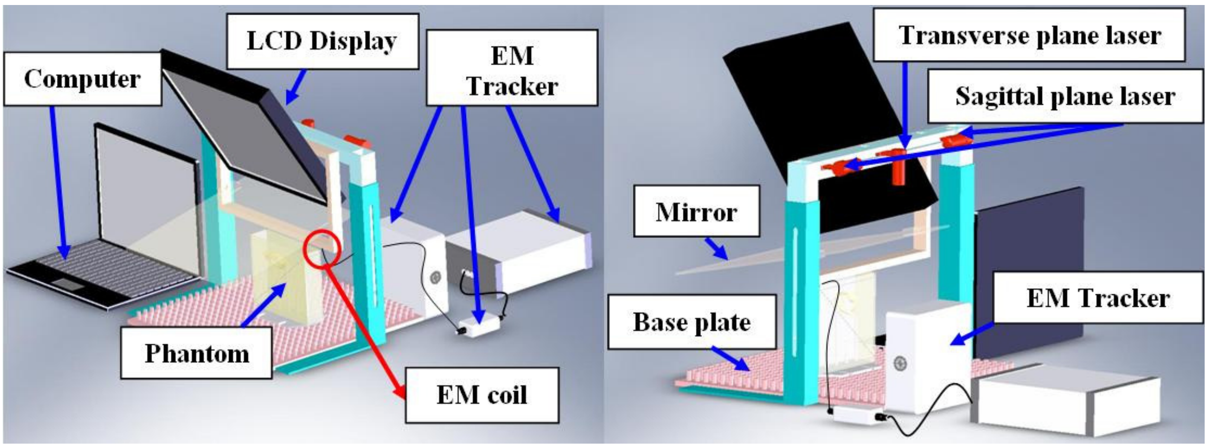

Fig. 1. CAD design of the Perk Station, w/ image overlay (left) and laser overlay & tracked navigation (right)

A detailed view of the Perk Station is shown in Fig. 2.

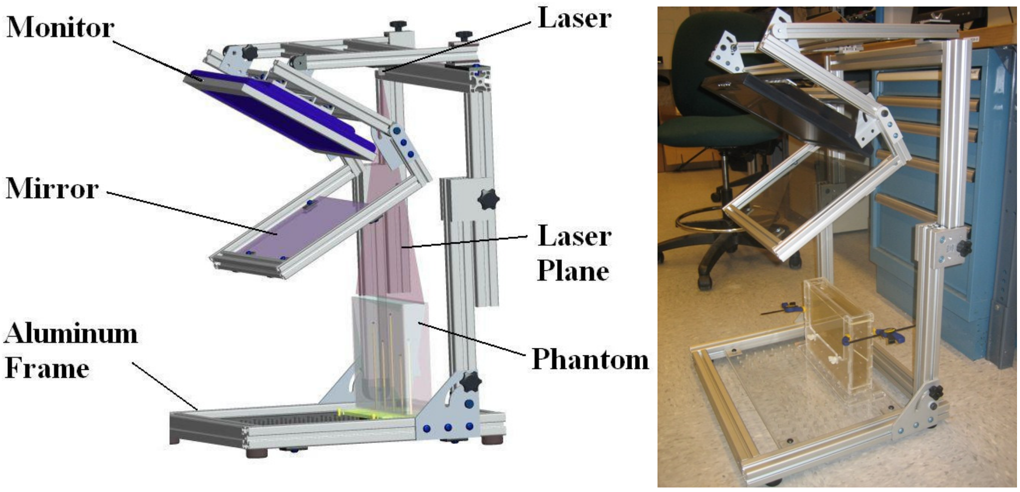

Fig. 2. Perk Station with Image Overlay unit – current design.

3. Phantom Design

Another important part of the system is the "real-time" nature of the phantom. The associated needle insertion phantom is made transparent and is designed to house various types of subjects. For example, in the embodiment made for practicing spinal pain management, the phantom comprises a human vertebra is embedded in different layers of gel representing muscle and fat, under a neoprene skin.

Geometrical or anatomical phantoms are housed in an interchangeable rigid box (inside box). A reusable external housing (outside box) is equipped with external markers (stereotactic fiducials and EM tracking coils), and can be easily realigned under the overlay as shown in Fig. 3. A "Z" shape pattern and 28 divot points are laser cut into the container to facilitate registration between the CT/MR and navigation space. The phantom is registered to navigation space with a calibrated electromagnetic (EM) tracked pointer. The NDI Aurora EM tracking system is used to localize an instrumented needle with respect to the phantom. An EM tracking coil or a 6 degree-of-freedom (DOF) reference tool is fixed to the phantom and a calibrated pointer tool is used for rigid-body registration of the phantom to the tracker. The needle hub and tip are also instrumented with EM tracking coil, so that we can analyze the user's motions and validate the accuracy of needle placement relative to the phantom (Fischer et al, 2007).

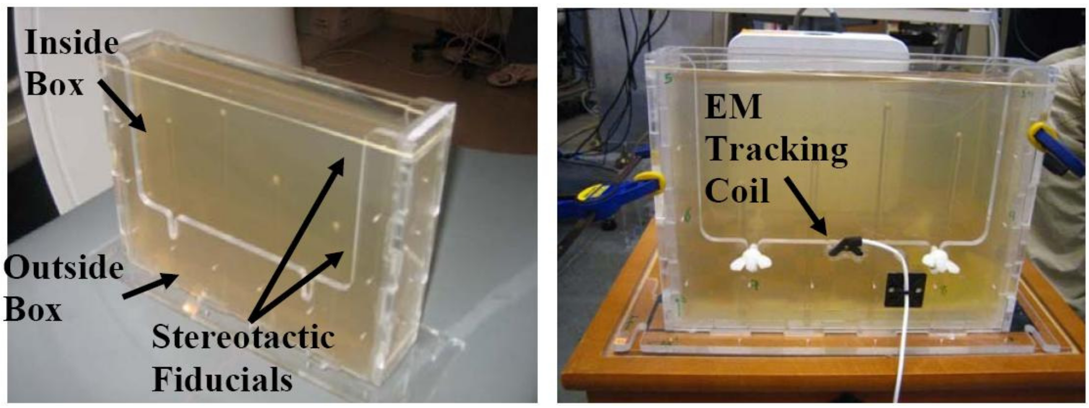

Fig. 3. The "real-time" phantom

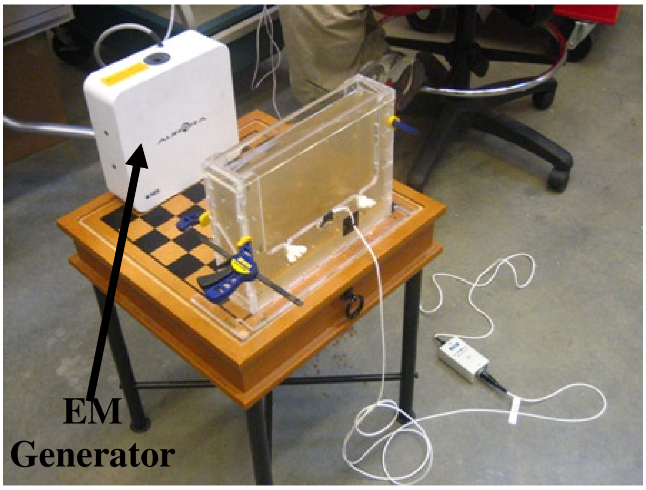

Fig. 4. Registering the Phantom to the Electromagnetic system

4. The graphical surgical interface

The graphical surgical planning and control interface will be integrated into the 3D Slicer, open source medical image computing and visualization software. The interface software combines functions and elements of image overlay, laser overlay and tracked navigation, as well as motion analysis and statistical performance metric tools. The software provides insertion and target point error, both in and out of the image plane. Needle axis orientation error is also computed.

5. Results

The Perk Station image overlay system as shown in Fig. 2 has been successfully designed and built. Preliminary evaluation tests and calibration procedures are ongoing. The first training phantom prototype that was designed and built with respect to the "real-time" conditions is shown in Fig. 3. The graphical interface software has been developed and used with the CT image overlay of the first phantom prototype as shown in Fig. 5 and 6.

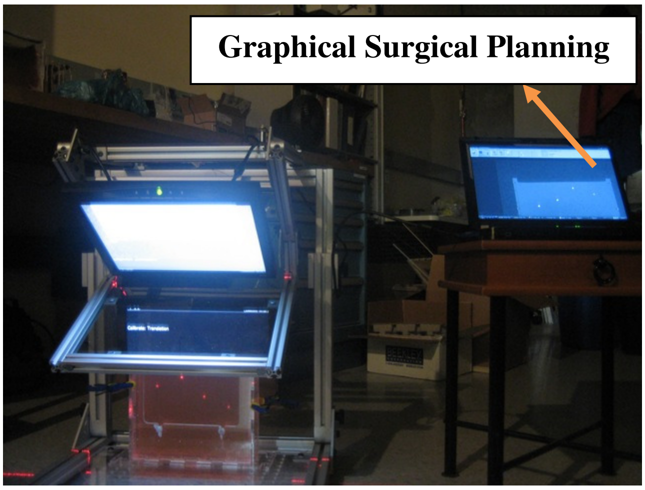

Fig. 5. The Perk Station, w/CT image overlay and the phantom.

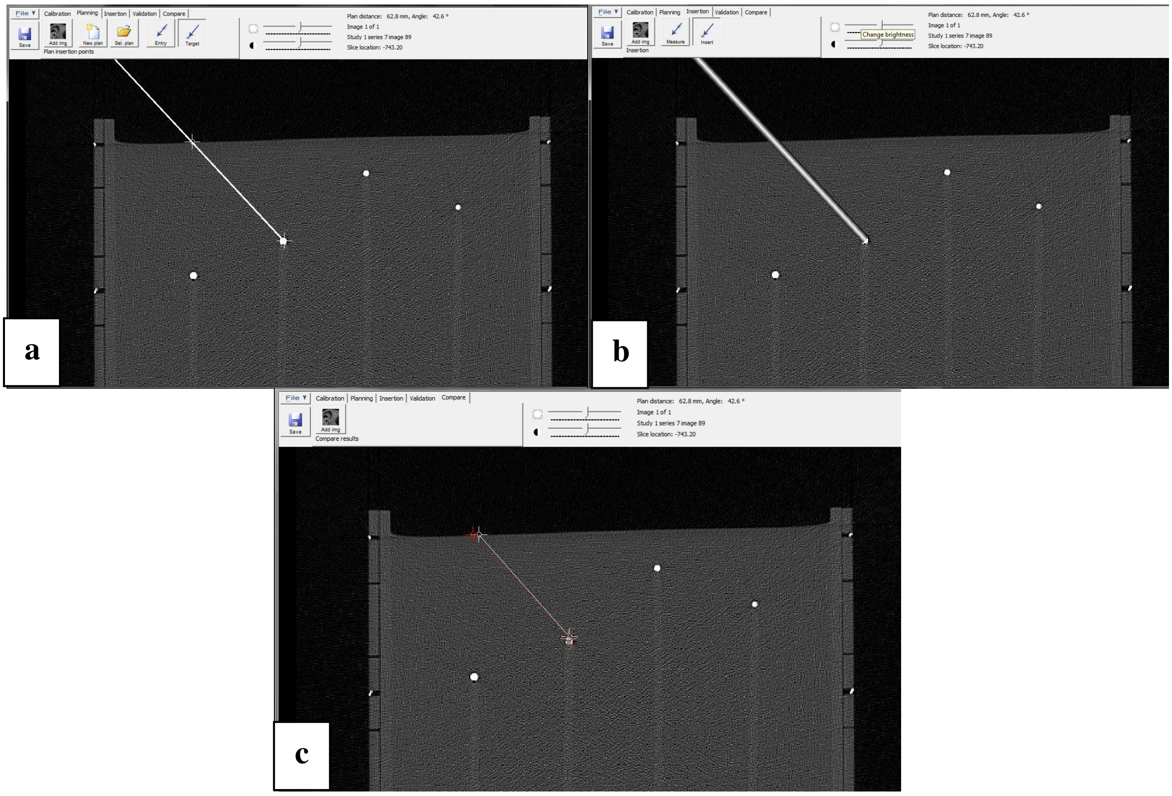

Fig. 6. The graphical interface software of CT image overlay; a) planning b) guiding path c) insertion and target point error

To promote transferability, the complete design of the Perk Station, including hardware blueprints, phantoms blueprints, and software source code will be made publicly available as open source. Simple design and low costs allows interested parties to replicate the hardware and install the software. The Perk Station is modular, so users can further downscale its functions and thus save on hardware. The distribution website will also supply medical image data and pre-made surgical plans so that users can operate the Perk Station without having access to medical imaging facilities. Documentation and tutorials will also be provided on the website.

6. Conclusions

The Perk Station is a replicable and adaptable tool for teaching computer-assisted surgery at all levels, from high-school science classes to clinical residency. It is small, portable, and light weight, and it fits in a suitcase when disassembled. The apparent simplicity of the Perk Station should not belie its potentials in teaching and training medical professionals, particularly medical students and residents. There is a general misperception and under-appreciation among the public of the skills required for needle based surgeries. In reality, trainees gravitate to learning centers where procedural skills are taught. There is also popular trend to minimize the steep learning curve by using simulations. Patients and patient advocates are less tolerant of training on clinical cases. Increased clinical workloads have also demanded increased provider productivity. The changing financial climate and commercial initiatives have catapulted to the forefront the need of training and performance evaluation without involvement of human subjects. Static or declining reimbursements have driven the need for economical solutions: training systems of with accuracy, efficiency, simplicity, and low cost. The Perk Station promises to fit in these trends eminently.

The Perk Station image overlay system has been successfully designed and built. Preliminary evaluation tests and calibration procedures are ongoing. The physical embodiment will be presented at the conference. The system will debut in undergraduate teaching in fall 2008.

7. Acknowledgements

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