Workspace Analysis and Calibration Method for Mobile Image Overlay System used for Image-Guided Interventions

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INTRODUCTION

Previously, a static image overlay guidance system has been proposed for aiding needle placement interventions [1,2]. In this technique, a 2D computer display image is reflected by a semi-transparent mirror, so that the virtual image appears floating inside the patient in correct 3D position. This system provides accurate transverse image guidance for musculoskeletal interventions of the shoulder, hip and spine [3,4]. The previous static mounting of the system was either fixed to the CT/MR imaging system [1] or on a floor-mounted frame over the patient table [2,3]. This mounting required careful calibration before each procedure, and was prone to misalignments due to structural deformation or unintended physical contact with the device. Furthermore, the static mount limited the access to the patient and excluded clinically relevant ranges of motions of the tool and the physician. To overcome those limitations, we propose the Mobile Image Overlay System (MIOS). The potential applications of MIOS are musculoskeletal needle injections, parathyroidectomy, percutaneous nephrolithotomy and percutaneous access to blood vessel.

MATERIALS AND METHODS

MIOS consists of mirror-monitor configuration called as viewbox similar to [1,2] and attached to a floor mounted articulated counter-balanced system. It is equipped with optical markers on the viewbox to measure the pose of the image overlay plane during the entire procedure. An optical marker (reference marker) is attached to the patient's skin, near the location of the intervention to allow tracking of the virtual image plane pose relative to the patient. A set of CT or MR visible fiducial markers are placed on the patient before image acquisition. These fiducial markers are touched using an optically tracked stylus to register the acquired image with the reference marker's coordinate system by using landmark registration. The system can be used for exploration of the image volume by a moving image slice overlaid on the patient. The software will display the correct image in real time corresponding to the position of the image overlay plane tracked by the tracker w.r.t the patient. After locating the target point in the image overlay plane inside the patient, the system is firmly locked in this position and the needle trajectory is drawn on the image slice in the software, which gets updated in the image overlay plane for needle guidance. MIOS overcomes the practical difficulty of accurately positioning the static image overlay system [1,2] by the motion tracking of the viewbox.

Workspace analysis: The spine needle injection and parathyroidectomy are the two critical procedures which defines the constraints for workspace analysis. Workspace analysis defines the i.) optimum angle between mirror and monitor for maximum viewing angle up to which the complete depth of the image overlay can be seen through the mirror and orientation of viewbox w.r.t articulated arm; ii.) directions of the required motion; iii.) sufficient gap between the viewbox and patient while the system is positioned over the patient; iv.) oblique rotation of +/- 35^{o} of the image overlay plane; v.) sufficient vertical space for needle injection. The study was conducted using CAD software "Creo2.0". Previously proposed 60^{o} system (Fig. 1a) in [1,2] and newly proposed 90^{o} system (Fig. 1b) are considered for the study.

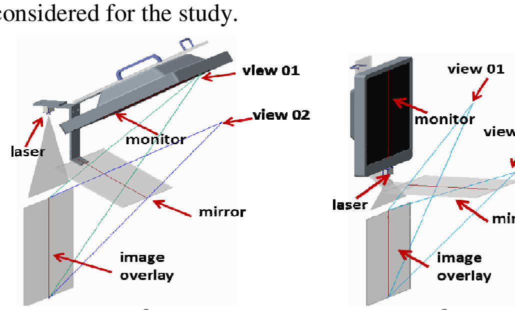

Figure 1a: 60^{o} MIOS Figure 1b: 90^{o} MIOS

Calibration method: The image overlay plane has to be registered to the image reslicing plane in the software and physical position of the patient. Two calibration methods were studied: i.) indirect calibration (Fig. 2) and ii.) direct calibration (Fig. 3). Indirect calibration is the conventional method and uses calibration phantom to register the image overlay plane with image reslicing plane in the software. It requires manual alignment of the viewbox until the markers in the virtual image appears in perfect alignment with the markers on the calibration phantom. The direct calibration method is a novel approach to register the image overlay plane directly to the image reslicing plane in the software, without the needs of physical calibration phantom. The tracker determines the pose of the passive markers on the viewbox and the virtual markers displayed in the image overlay plane. The transformation matrix is determined between image overlay plane and viewbox from the maker pose measured. During the procedure, the viewbox is continously tracked by the tracker and using the computed transformation matrix, the actual position of image overlay plane relative to the patient is determined.

For oblique image display, three concepts were studied: i.) five bar link mechanism; ii.) monitor rotation only; iii.) viewbox rotation about fixed target axis (Fig. 5).

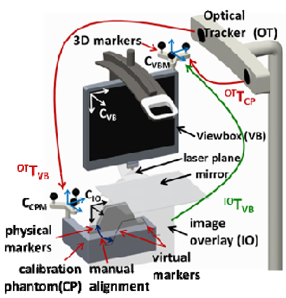

Fig. 2: Indirect calibration

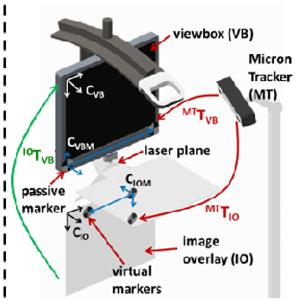

Fig. 3: Direct calibration

RESULTS

The workspace analysis reported the newly proposed 90^o system (Fig. 1b) to be optimal with viewing angle up to 35^o as compared to 15^o for the previously proposed 60^o system (Fig. 1a). For oblique images, the rotation of the whole viewbox (Fig.5) was practically feasible as compared to five bar link mechanism or monitor rotation concept. The requirement of +/- 35^o oblique rotation was not satisfying with both concepts due to reduced user viewing angle and mirror interference with the patient. The optimal oblique rotation angle is +/- 15^o and it will be considered as a limitation of the MIOS. Alternatively, the system can be rotated about 90^o around the vertical axis to view the oblique details in the image overlay plane.

The conceptual view of the MIOS is shown in Fig. 4 and the first prototype developed is shown in Fig. 6. The system shall have four directions of motion as shown in Fig. 5: i.) movement of +/-5cm along longitudinal axis; ii.) rotation of +/-90 ^{o} about vertical axis of the image plane; iii.) oblique rotation of +/-15^o about the target point of needle insertion and iv.) movement of +/-10cm along vertical axis to accommodate patients of different abdominal size.

The 90^o system has additional benefits compared to the 60^o system: i.) increased clearance between mirror and the patient; ii.) reduced system inertia as the system is mechanically balanced about the image overlay plane and iii.) increased viewing angle which also improves the view ability for tracker.

The direct calibration method is expected to reduce the calibration time with simplified calibration steps. Direct calibration can be done away from the patient space and doesn't require initial phantom calibration step.

DISCUSSION

Based on successful pre-clinical testing of the static image overlay system [3,4], MIOS promises to become an even more useful tool for image-guided surgical navigations. The mechanical design of the MIOS needs to be worked further for precise movement of viewbox along longitudinal and patient vertical axes, enable the viewbox rotation to view oblique images up to +/- 15^o. Phantom and cadaver studies need to be performed to evaluate the accuracy of direct calibration method and to refine the clinical workflow. The initial studies shall focus on procedures with negligible effect of respiratory. However it is possible to compensate the effect of respiration as the patient-attached markers are constantly tracked by the tracker.

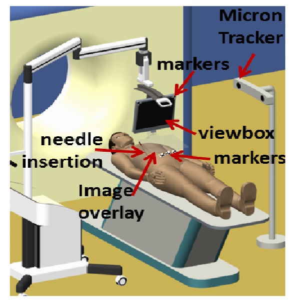

Fig. 4: MIOS concept

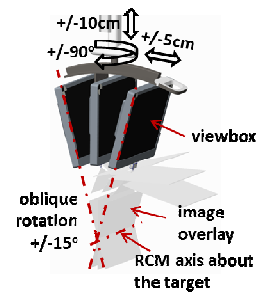

Fig. 5: Ranges of motion

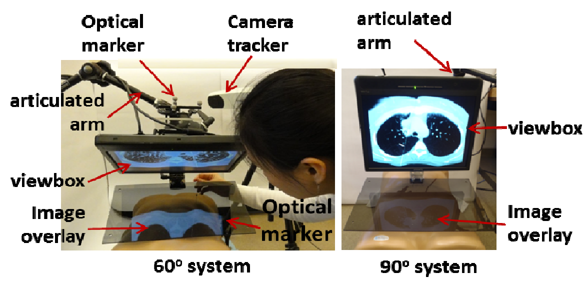

Fig. 6: MIOS prototype

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