Feedback Control of a Patient-Mounted Telerobot using Electro-magnetic Tracking of Needle Angle

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Purpose

This paper focuses on demonstrating the feasibility of using the Robopsy device with the Ascension electro-magnetic (EM) tracking system (MedSAFE, Ascension Technology Corporation, Burlington, VT, USA).

Methods

The Robopsy device is a lightweight, largely plastic telerobot (shown below in Fig. 1A) that affixes directly to a patient's chest to pivot the needle in two degrees of freedom about a skin insertion point [1]. This is accomplished via two motor-actuated concentric, crossed and partially nested hoops. A medical image-based interface converts doctor clicks on the DICOM images to motor commands that align the needle along the desired trajectory and subsequently insert it. [2]. The kinematic equations to determine the motor commands to align the current needle trajectory with its desired trajectory are outlined.

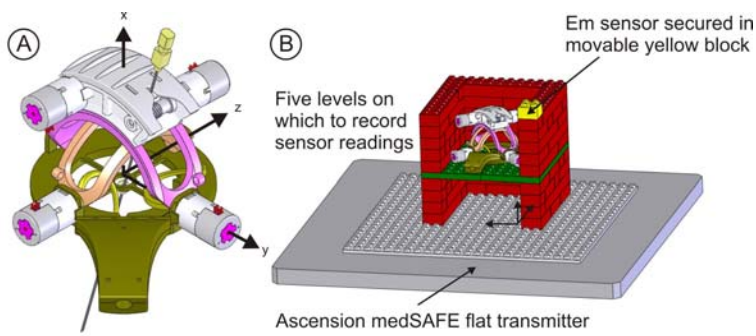

Fig. 1 In A), the Robopsy device is shown with its two hoops that create the spherical mechanism for orientating the needle to a desired compound angle. The origin of its coordinate system is at the intersection of the two motor axes (z and y axes). In B) custom rig that was used to calibrate the electro-magnetic tracking system and determine the distortion effects due to the presence of the robot. The LEGO structure enabled one brick (yellow) with an embedded sensor to be positioned accurately at different heights along the "U" path.

Using the tracking system, the current position and orientation of the needle was determined by embedding a six degree of freedom 1.2 mm EM sensor into the head of the needle. In order to determine the feasibility of using the MedSAFE tracking system from Ascension Technologies it was first necessary to verify its accuracy and any distortion due to the robot in its working volume. For this purpose, a custom LEGO™ calibration rig was built and attached at a fixed location to the flat-plate of the tracking system (Fig. 1B) and a single sensor embedded in a LEGO™ block was moved along a known path at different heights. Previously it has been shown that the repeatability of placing LEGO™ blocks is less than 5 µm [3]. A custom angular calibration rig (not shown) was used to determine the angular accuracy. A digital proportional-integral (PI) controller was implemented in Matlab™ to control the angular position of the two hoops based on the current needle angle and an input desired angle. The gains were tuned based on the open loop response using the Chien, Rhones and Reswick (1952) method.

Results

Initial measurements with the tracking system demonstrated that a coordinate transform was required to align the tracking system coordinates with the LEGO™ structure. The coefficients for the transform were found with a least squares optimization using Matlab™ with the assistance from staff from Ascension. This transform was subsequently applied to all data before making any accuracy or needle positioning experiments. The mean RMS accuracy of the tracking system was found to be 0.25 mm and 0.85 mm without and with the robot in the working volume respectively. Fig. 2A shows a plot of the ideal sensor position (blue) and the tracking system readings (red). While the robot clearly caused distortion of the readings from the tracking system, qualitatively we observed that the distortion was not significant and only localized to the vicinity of the stepper motors. Using the custom angular calibration rig (not shown) we found that the angular accuracy was 0.1 degree.

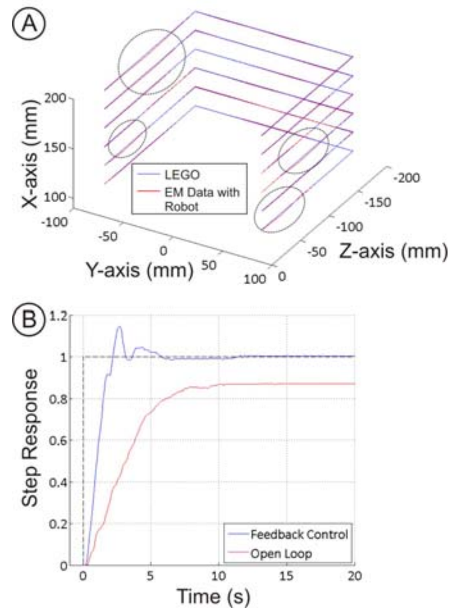

Fig. 2 3D representation of expected and EM sensor measurements from the tracking system with the Robopsy device present. Open and closed loop step response in Y-hoop normalized by the angle of rotation.

Fig. 2B shows the normalized response of the needle position to an angle step input for the open-loop (red) and close-loop case (blue). Using the digital PI controller the system was successfully able to position the needle at the desired angle with zero steady state error.

Conclusion

This preliminary study demonstrates the feasibility of using readings from an electromagnetic sensor to control the orientation of a needle with the Robopsy system. Incorporating the Robopsy device the existing clinical tracking system could be useful when very precise angulation or medical instrument support is required.

References

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