Synopsis: Closed-Loop Active Compensation for Needle Deflection and Target Shift During Cooperatively Controlled Robotic Needle Insertion

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***Abstract*—The abstract by Will goes here.**

***Index Terms*—IEEE, IEEEtran, journal, LATEX, paper, template.**

I. Introduction

THIS demo file will be edited by Will. It is intended to serve as a "starter file" for IEEE journal papers produced under LATEX using IEEEtran.cls version 1.8b and later. I wish you the best of success.

mds
February 7, 2023

A. Subsection Heading Here

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II. Methods and Materials

Sample text inside input file for Part 1 of materials and methods.

A. Feature Localization

For evaluation of the closed-loop active compensation during cooperatively controlled needle insertions, we use two cameras to capture real-time images of the needle tip and target within the robot workspace. This is a suitable substitute for medical imaging, in fact the compensation technique is not dependent on the modality of the medical image. The two cameras are placed orthogonal to each other, and are run by a standalone software application.

In the software application, we employed Farnebäck's algorithm [1] to execute on captured video frames to localize the moving needle tip and obtain homogeneous transformations of the tip and the target. We used a color segmentation technique to demonstrate the active compensation.

B. Active Compensation

Before any targeting takes place, registration is performed by rigidly attaching a marker to the robot. For example, we would attach the marker with MR visible fiducials when moving through an MRI machine. This is visually supported by Figure 1.

All authors are software engineers in their professional life.

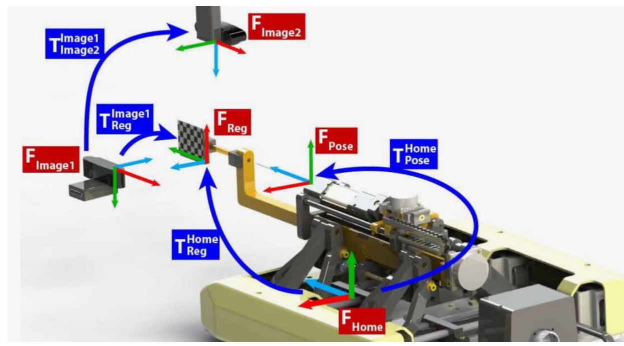

Fig. 1. Frames and transformations for image guidance registration

After the registration is complete, the marker is removed. The OpenIGTLink [2] communication protocol is used to pass down the frame and transformations from image-guidance software to the robot controller. As seen by Figure 1, the transformation sequence $T_{Pose}^{Home^{-1}} T_{Reg}^{Home^{-1}} T_{Reg}^{Image^{-1}}$ is used to express the registration with respect to the robot pose.

Throughout the insertion, the robot continuously receives the tip and target locations with respect to the image. Using the known transformation matrices, it determines the tip and target with respect to the robot pose. Naturally it can then compute the target location with respect to the tip, or T_{Target}^{Tip}. This tells us our desired compensatory effort.

To achieve this compensatory effort in all the insertion trials of our work, we chose to use Gang Li's novel CURV model [3], where both magnitude and direction of the desired effort can be implemented. Assume that θ is the current rotational angle of the bevel, and θ_d is the desired angle of the bevel for compensation. At any angular position, we can use the following equation.

$$\hat{\omega}(\theta, \theta_d) = 1 - \alpha e^{-\frac{(\theta-\theta_d)^2}{2c^2}} \tag{1}$$

Equation 1 gives the angular velocity as a function of θ and θ_d. Here, widening the Guassian width c gives a bigger range of angles where rotation occurs below the nominal velocity. Also, increasing the Guassian magnitude α leads to more deflection in θ_d. The authors of this synopsis recommend referencing Gang Li's excellent disseration [3] for the angular velocity profile graph of CURV. While CURV was used in this work, it is possible to use other bevel tip based curvature models.

To calculate the θ_d in our case, we used the $atan2$ function on the x and y positions obtained from T^{Tip}_{Target}. We set c is Equation 1 to 10° for all insertions. The α was chosen as an intermediate curvature value by projecting the needle tip orientation onto the target plane. For projecting the orientation, we first found the Euler angle rotation about the x and y axes, and then used the following equations,

$$X_{projected} = D_i \times \arctan(Rot(y)) \tag{2}$$

$$Y_{projected} = D_i \times \arctan(Rot(x)) \tag{3}$$

Where D_i is the remaining insertion depth.

III. Results

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IV. Discussion

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Appendix A
Proof of the First Zonklar Equation

Appendix one text goes here.

Appendix B

Appendix two text goes here.

Acknowledgment

The authors would like to thank...

References

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[2] J. Tokuda, G. S. Fischer, X. Papademetris, Z. Yaniv, L. Ibanez, P. Cheng, H. Liu, J. Blevins, J. Arata, A. J. Golby, T. Kapur, S. Pieper, E. C. Burdette, G. Fichtinger, C. M. Tempany, and N. Hata, “Openigtlink: an open network protocol for image-guided therapy environment,” *Int J Med Robot*, vol. 5, no. 4, pp. 423–34, 2009 Dec 2009.

[3] G. Li, “Robotic system development for precision mri-guided needle-based interventions,” 2016.

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Patrick Donelan Biography text here.

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Debbie Guenthner Biography text here.

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Will Yingling Biography text here.