Preliminary evaluation of haptic guidance for pre-positioning a comanipulated needle

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In minimally-invasive procedures like biopsy, the physician has to insert a needle into the tissues of a patient to reach a target. Currently, this task is mostly performed manually. This can result in a large final positioning error of the tip that might lead to misdiagnosis and inadequate treatment. In this paper, we present 5 haptic guides to assist the clinical gesture of needle insertion. Those guides were evaluated through a preliminary user study involving two physicians, both experts in needle manipulation.

1 Introduction

Percutaneous needle insertion is frequently used for diagnosis or treatment and the outcome of those minimally-invasive procedures depends almost exclusively on the accuracy of the placement of the tip of the needle on an anatomical target. Inaccurate positioning may force the physician to perform the insertion again, thus increasing the duration of the intervention and discomfort for the patient. Currently, needle insertion is mostly performed manually, which is prone to error for several reasons [1]. Among those, the interaction forces between the needle and the tissues [2][3], make it nearly impossible to correct the trajectory of the needle once it is inside soft tissues. Therefore, correct pre-positioning of the needle is essential. To make needle pre-insertion more precise and reliable, one idea is to provide the physician with robotic assistance. In this paper, we propose 5 haptic guides dedicated to comanipulated-needle pre-positioning and inspired from guiding virtual fixtures [4] [5]. They are designed to attract the physician towards the entry point and the correct orientation, while ensuring close proximity with the patient.

2 Methods

We present 5 haptic guides denoted by FTip, TTip, FTTip, FTATip and TEff and illustrated in figure 1. The unassisted reference gesture is denoted by Ref. Each haptic guide produces a 6x1 force-feedback vector, computed either in the needle-tip frame or the end-effector frame of the haptic device. This force vector is computed from the pose error between the current measure of the pose of the needle-tip frame (or the end-effector frame) and the desired pose of the entry-point frame. The latter is centered on the entry point and its z axis corresponds to the desired angle of incidence to reach.

FTip constrains the position of the tip of the needle, to keep it close to the normal of the tissue surface that crosses the entry point. So, the tip can be translated along the normal, but as soon as it deviates from it, a lateral force $\mathbf{f}_{\text{lateral}}$ is generated to pull it back. Translations along the z axis and rotations around the yaw, pitch and roll axes of the tip frame are free. TTip constrains the orientation of the needle to the desired angle of incidence, regardless of the current position of the tip. Thus, it applies a torque $\mathbf{t}_{\text{tip}}$ to the needle, around the yaw and pitch axes of the tip frame. All the translations and the rotation around the roll axis of the needle are free. FTTip combines FTip and TTip, i.e. $\mathbf{f}_{\text{lateral}}$ and $\mathbf{t}_{\text{tip}}$, to constrain both the position and the orientation of the needle. Only translations along the z axis and rotations along the roll axis of the tip frame are free. FTATip adds an attractive force $\mathbf{f}_{\text{attraction}}$ to the force-feedback vector of FTTip. It is computed in the tip frame and oriented towards the entry point. With FTATip, only the rotations around the roll axis of the tip frame are free. TEff ensures the needle always points toward the entry point, by applying a torque $\mathbf{t}_{\text{eff}}$ to the yaw and pitch axes of the end-effector frame of the haptic device.

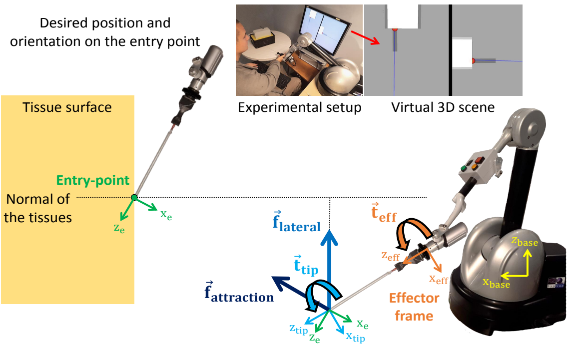

Figure 1: *The five proposed haptic guides and the experimental setup of the preliminary user study. The blue arrows represent the needle-tip frame, as well as forces and a torque expressed in this frame. FTip, TTip, FTTip and FTATip implement one or a combination of those forces and torque. The orange arrows represent the end-effector frame of the haptic device and a torque expressed in this frame, which is implemented by TEff.*

3 Prelimary user study and results

We conducted a preliminary user study to compare the 5 haptic guides and the unassisted reference gesture. It involved an interventional radiologist and an anaesthetist, both experts in needle manipulation. Our evaluation focused on the performance of the physicians for pre-positioning a needle before its insertion into soft tissues, but also on user experience. The task consisted in positioning a needle on a target in 3D space and under a desired orientation. The participants handled an instrumented needle, tracked electro-magnetically by an Aurora$^{\text{TM}}$device, (Northern Digital Inc., Ontario, Canada). The needle was attached to a 6-DOF haptic device (Virtuose$^{\text{TM}}$6D, Haption [6], France) (see Figure 1). A computer screen displayed a simulated version of the real scene. The physicians were asked to place the tip of the needle on a green virtual sphere representing the entry point, and to give the axis of the needle a desired angle of incidence represented by a grey virtual cylinder. The latter was achieved by keeping a blue line, representing the needle, parallel to the grey cylinder displayed on the screen.

Performance-wise, the best positioning accuracy was obtained with TTip for both physicians, with improvements of 54% for the first one and 20.4% for the second one, compared to Ref. However, less obvious results were achieved in terms of orientation accuracy with the guides. Overall, TTip comes out as the best for both physicians with regard to positioning accuracy. The goal of the subjective study is to compare the 5 haptic guides and the unassisted reference gesture from a user-experience point of view. The criteria are the level of assistance, accuracy, ease of use, comfort and usefulness of haptic feedback. The physicians filled a subjective questionnaire after performing the task with the guides or Ref, answering questions within a 7-point Likert scale. At the end of the experiment, they were also asked to choose the approach they preferred and the one they enjoyed the least. The results of the subjective study are presented by the radar charts in figure 2. Those indicate that the methods the physicians preferred are TEff and FTip and that the ones they enjoyed the least are FTTip and Ref.

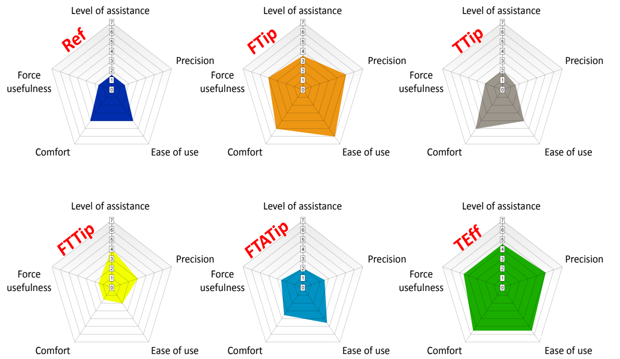

Figure 2: *Radar charts presenting the results of the subjective comparison of the 5 haptic guides and the unassisted reference gesture*

4 Discussion and conclusion

The objective and subjective study showed that the positioning accuracy was enhanced with haptic guidance, with improvements of 54% for the first participant and 20.4% for the second one, compared to Ref. The outcome of the study was less conclusive in terms of orientation accuracy, however. In the questionnaire, both participants stated about TEff, i.e the haptic guide they enjoyed the most, that it was comfortable and precise. The first user noted that it was very helpful at the beginning of the task, for correctly orienting the needle toward the target, and that it did not disturb accurate positioning closer to the target. The other added that it enabled good handling of the needle with a good amount of stiffness, which facilitated accurate positioning. They also enjoyed FTip. On the contrary, they were less satisfied by Ref, FTTip and FTATip. It appears that they preferred to be in control of the final orientation of the needle, while at the same time receiving soft feedback from the haptic device, for comfortable needle positioning.

Those promising results open possibilities for increasing the level of accuracy and reliability of needle pre-positioning and pre-orienting. It also paves the way for the design of efficient haptic guides dedicated to comanipulated needle insertion in soft tissues.

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