Live Demonstration: Haptic-Enhanced Bioimpedance Needle for Assisting Central Venous Catheterisation

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***Abstract*—This work introduces a unique bioimpedance (BIOZ) guided haptic needle technology designed to enhance central venous catheterisation (CVC) procedures. The portable system combines real-time BIOZ analysis, needle posture tracking, and a haptic device specifically developed for CVC research. By providing real-time haptic feedback and BIOZ analysis, the system significantly improves precision, ensuring a 100% success rate for vein entry. During the demonstration, visitors will first experience the challenges of CVC without assistance. Then, using the platform, they will experience how the system improves accuracy by guiding the needle into a phantom of the vein, greatly increasing the insertion success rate.**

I. Introduction

Central venous catheterization (CVC) involves inserting a catheter into central veins for treatment. Currently, the prevalent solution in hospitals is to use ultrasound imaging to perform multi-angle scanning of the vein and needle, both transversely and longitudinally. However, a major limitation of this method is its reliance on the clinician's skill level. Inexperienced clinicians often misplace the needle, leading to complications, with an incidence rate as high as 20% [1]. Bioimpedance (BIOZ) is a proven technique for distinguishing between various biological tissues, showing significant promise for assisting needle positioning. Despite several methods being proposed [2], several major challenges remain. Impedance drift in commercial bipolar electrodes due to charge accumulation affects measurement accuracy. Additionally, the compatibility of large robotic arms and multi-sensor systems with CVC procedures remains limited. These problems continue to hinder the development of next-generation CVC technology.

This live demonstration presents a BIOZ needle handle (BiNH) with tetrapolar electrode probes (Nano Dimension, USA) for real-time needle tip posture and BIOZ analysis [Fig. 1 (a)]. The haptic mesh is updated simultaneously to provide real-time force feedback. The haptic feedback and graphical user interface (GUI) help the operator accurately position the needle at the centre of the vein.

II. Demonstration Setup

Fig. 1 shows the proposed CVC assistive platform [3], which comprises the following components:

- **BiNH:** The handle, equipped with BIOZ probes.
- **Inverse3 (Haply Robotics, Canada):** The haptic device can deliver force feedback to the BiNH.
- **Laptop**: Executing the real-time needle tip tracking algorithm, constructing the force mesh, and operating the GUI to display indicators and plots.

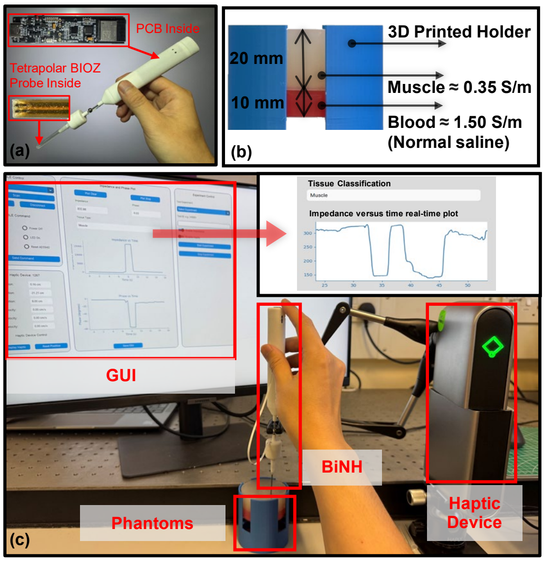

Fig. 1. (a) The BiNH components. (b) Test phantom setup. (c) Overview of the CVC assistive platform.

- **Phantoms**: The phantoms mimic muscle and blood conductivities. A side view is shown in Fig. 1 (b).

III. Visitor Experience

This demonstration allows visitors to experience the challenges of a CVC procedure. Initially, they will perform an insertion test using the BiNH and haptic device without any assistance, and the final insertion results will be displayed on the GUI. Next, with the system assistance activated, visitors will operate the BiNH again, allowing them to experience varying insertion forces during the simulated CVC procedure. The haptic device will simulate the resistance of different tissue types, guiding the user to accurately insert the needle into the phantom (emulating the centre of the vein). If the needle penetrates beyond the vein, the system will generate strong force feedback to prevent further movement. Simultaneously, real-time tracking of the operation, including BIOZ, haptic forces, and tissue classification, will be displayed on the GUI.

References

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