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INCREMENTAL NEEDLE INSERTION SYSTEM FOR FORCE AND POSITION SENSING

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ABSTRACT
An Incremental Needle Insertion System (INIS) which simultaneously measures the force and position of a needle during insertion was designed and fabricated for use in a tissue deformation study to improve realism in medical simulation. The INIS was tested in a fresh frozen cadaver experiment and the position of the needle was plotted and compared to the expected needle path. It was found that the INIS is sufficiently accurate with an average path deviation of 1.55 mm. In addition, INIS was shown to successfully measure the maximum Central Venous Catheterization needle insertion force which ranged from 3.02 N to 3.73 N.

Keywords: Needle insertion, Medical simulation

1 Introduction
Medical simulation training provides a method for medical and surgical residents to practice complicated procedures repeatedly in various scenarios without the need for real patient involvement. This allows the resident to learn from their mistakes without causing any discomfort or danger to a patient [1]. Simulation training can only be effective if the environment produced by the simulation device accurately represents the real case [2-4]. Thus, to better simulate the real scenario, recent studies have been conducted to incorporate haptic force feedback into medical simulators [5]. Simulation haptics has been employed in state-of-the-art devices for simulating femoral palpation, laparoscopic surgery, and endoscopy [6-8]. The Dynamic Haptic Robotic Trainer (DHRT) for Central Venous Catheterization (CVC) shown in Fig. 1 has been developed to simulate the forces involved with needle insertion into the internal jugular vein and utilizes a haptic robotic arm with simulated ultrasound guidance [9].

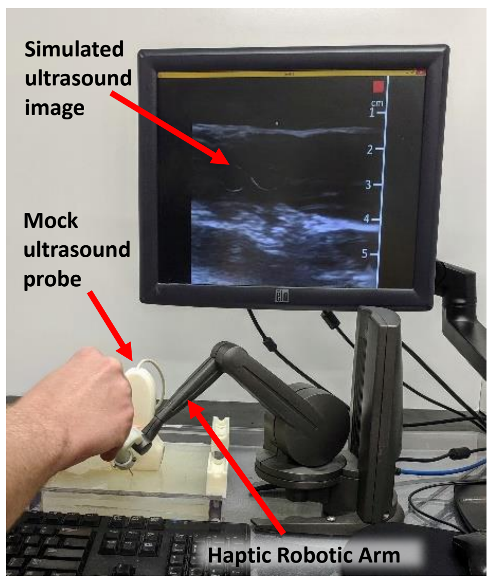

FIGURE 1: Dynamic Haptic Robotic Trainer developed for medical CVC insertion training

For high fidelity training development in CVC there has been minimal work in accurately relating needle force to ultrasound tissue deformation. In order to produce more accurate ultrasound simulation and haptic feedback in the DHRT simulator, a device for accurately measuring needle insertion was created to acquire both needle position and force information during cadaver experimentation. This paper outlines the design of this Incremental Needle Insertion System (INIS), which incrementally inserts a needle into tissue while simultaneously collecting force and position data. The stability and force results of employing this device in a cadaver experiment are presented and discussed.

2 Methods

The INIS was designed and fabricated as shown in Fig. 2 and utilizes an ATI Industrial Automation (Apex, NC) Nano17 6-axis force transducer. This transducer allows for accurate force and torque measurements in all directions, which are collected using a National Instruments (Austin, TX) PXIe-6361 data acquisition unit used in conjunction with LabVIEW. The device employs a Northern Digital Inc. (Waterloo, ON) 3D Guidance TrakSTAR Model 800 electromagnetic probe to measure the needle position. The device has a telescoping tube and spring system with an M5x175 mm linear screw allowing for accurate and consistent insertion depths at increments of 5 mm per full knob rotation. At full extension the needle depth is 90 mm. The small Jacobs chuck on the front of the device allows needles from 11 to 34 gauge to be mounted. The device was mounted to a Samson Technologies articulating arm, allowing it to be easily positioned to various insertion sites while retaining rigidity during the insertion procedure.

The INIS was utilized in an experiment to simultaneously track force and position data during 5 needle insertions into a fresh frozen cadaver. An elderly, male, un-embalmed, fresh frozen cadaver was acquired for the experiment. In consistency with the needs of the DHRT simulator, needle insertion force and position information was collected for needle insertion into the internal jugular vein in 2 subgroups: 2 incremental needle insertions, and 3 full needle insertions. In the first subgroup, the needle was brought to the skin at the desired site. While recording both force and position, the needle was inserted 5 mm, the tissue deformation was observed using an ultrasound probe, and the needle was advanced another 5 mm. This procedure was repeated until a depth of 30 mm was reached. In the second subgroup the needle was inserted to the full depth of 30 mm while simultaneously recording force and position. A professional vascular surgeon was consulted and involved throughout all procedures.

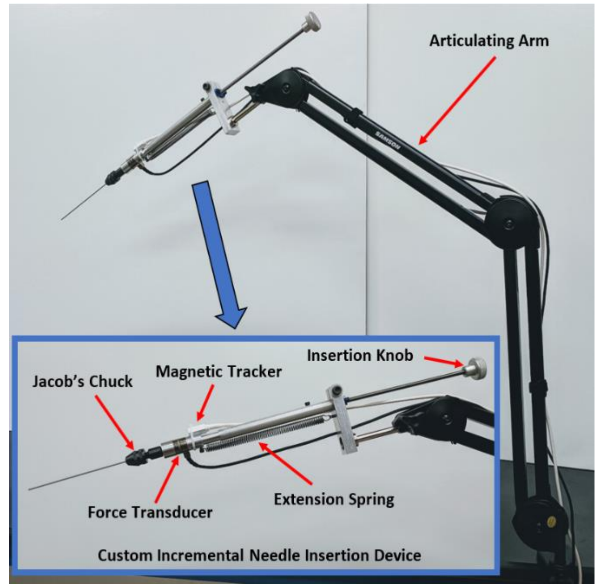

FIGURE 2: Incremental Needle Insertion System (INIS)

3 Results and Discussion

The maximum axial force on the needle recorded during each insertion can be seen in Table 1. The force transducer has a resolution of 3.125 mN. As expected, the forces for both the full and incremental needle insertions were similar as captured by the device.

Table 1: Maximum axial force of 3 full needle insertions and 2 incremental needle insertions

Insertion	Max Axial Force (N)
Full Insertion 1	3.73
Full Insertion 2	3.56
Full Insertion 3	3.08
Incremental Insertion 1	3.54
Incremental Insertion 2	3.02

Figure 3 shows the path line of the needle as recorded by the position sensor in comparison to the expected path. A projected straight-line path was found by taking the position and orientation of the needle at the beginning of each insertion and creating a parameterized equation of a 3D straight-line of insertion.

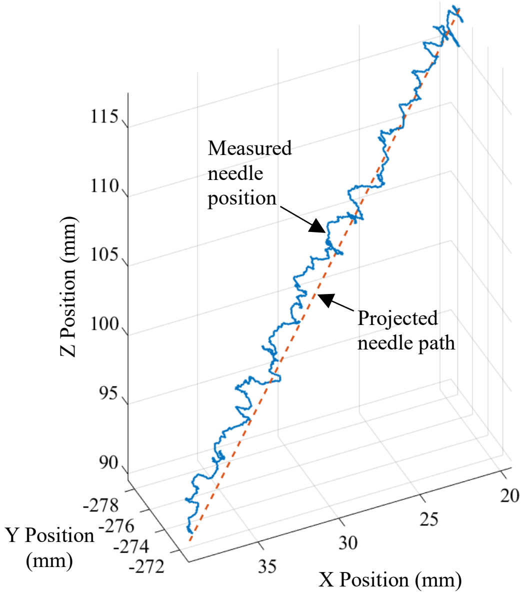

FIGURE 3: 3D position of a needle insertion as measured by INIS

The deviation of each point from the expected needle path was calculated. Figure 4 shows the average deviation from the projected path for both full and incremental insertions. As shown, the incremental insertions had a greater average deviation and greater variance compared to that of the full insertions. This greater inaccuracy was anticipated because, during an incremental insertion, the device comes in and out of human contact numerous times, which produces greater outside forces on the device that negatively impact stability. The average measured deviation from the expected path was 1.55 mm across all cases. There are numerous variables that influence the path deviations, including: slight movement in the articulating arm joints, needle bending within the tissue, and minor translational movements in rotating the lead screw during incremental advancement.

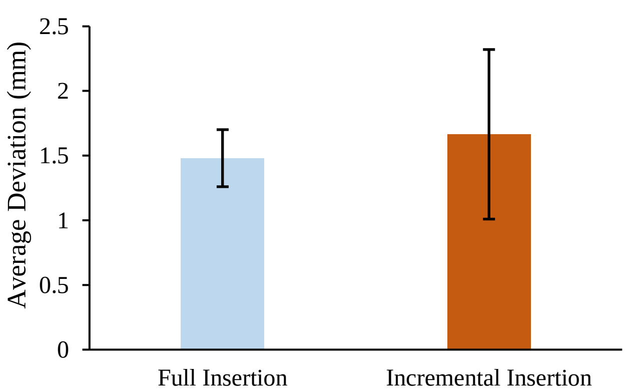

FIGURE 4: The average deviation of a 30 mm deep needle insertion from the expected straight-line path.

Despite these imperfections, the fact that the path deviation is small reveals that the INIS device is appropriate for studies involving tissue deformation, because the average deviation from a straight-line path is less than the deviation that a human would produce when attempting a straight-line insertion due to natural tremor which increases with fatigue [10-11].

4 Conclusion

The INIS device was presented and experiments were successfully performed. INIS was able to successfully measure CVC needle insertion force and was sufficiently stable. The system described will be used to accurately gather needle insertion information which will then be applied to improve fidelity and, thereby learning potential, in medical needle training systems.

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