IV Tutor: IV Insertion Training Module

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PROBLEM DESCRIPTION

Intravenous (IV) insertion is vital for up to 80% of hospital inpatients worldwide [1]. Despite its ubiquity, the procedure is plagued by a substantial failure rate ranging from 30% to 50% [2]. Insertion failure can lead to complications, including arterial or nerve damage, hematoma, and bleeding at the insertion site. Of the successfully placed IV lines, up to 50% may eventually fail before reaching clinical obsolescence [1]. The pervasive failure not only impacts patients and caregivers but also imposes substantial economic burdens on the healthcare systems, necessitating urgent strategies for improvement. An image of a correctly inserted peripheral venous catheter can be seen in Figure 1.

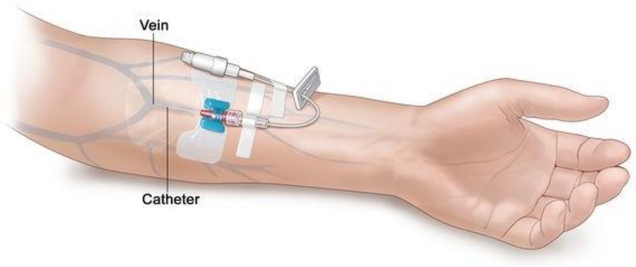


Figure 1: Image of a successfully inserted peripheral venous catheter.

DESIGN RATIONALE

Training device made from low-cost accessible materials

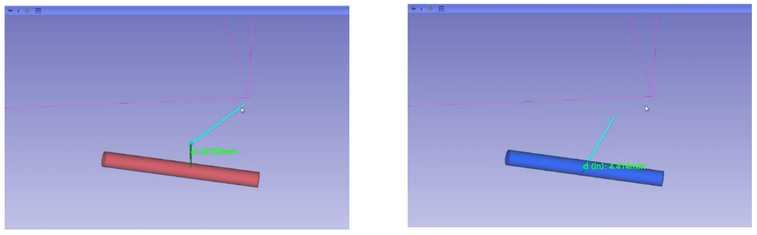
Track the 3D positions of the needle and arm to provide real-time positional data

Use 3D Slicer to provide an educational GUI to guide users through the IV insertion procedure

Give physical feedback of needle insertion to user

DESIGN SOLUTION

IV Tutor combines a physical 3D-printed arm model with a virtual guidance system to help the user improve their IV insertion techniques. IV Tutor uses the webcam and ArUco markers for precise 3D tracking to display the needle movement in real-time in 3D Slicer, a user-friendly, free medical software. This software is linked with the webcam through PLUS software to accurately capture the needle's position, offering immediate visual feedback and instructional guidance. The software provides a 3D view of the arm, vein, and needle, as well as the distance of the needle tip to vein in mm. When the needle is inserted into the vein, the vein will turn red in 3D Slicer to indicate a successful insertion. Removal of the needle from the vein or an unsuccessful attempt will result in the vein turning blue in 3D Slicer. In addition to this data, ten steps detailing the proper technique for IV insertion are displayed on the left-hand side of the user interface. Finally, there is a disconnect and connect device button to control the webcam. The vein in 3D Slicer after a successful insertion can be seen in Figure 2 A), and after an unsuccessful insertion can be seen in Figure 2 B).



A B

Figure 2: A) Screen capture of the vein in 3D Slicer after a successful insertion. B) Screen capture of the vein in 3D Slicer after an unsuccessful insertion.

The mechanical model is an anatomically accurate arm designed in SOLIDWORKS that was 3D printed. Neoprene fabric was adhered to the insertion site using epoxy to imitate skin. The fabric is porous, allowing for continual IV insertion with minimal wear. A support piece for the optical trackers was designed in SOLIDWORKS and 3D printed, allowing the webcam to connect and display the 3D model in 3D Slicer. The forearm of the model is removable with a magnetic connection, allowing for access to the electrical component assembly. The SOLIDWORKS model of the arm can be seen below in Figure 3 A), and the 3D printed prototype including the electrical assembly can be seen in Figure 3 B).

A B

Figure 3: A) CAD model of the phantom arm with a removable forearm. B) 3D printed prototype of the phantom arm and removable forearm.

All the electrical components are housed within the arm and can be accessed via the removable forearm. An Arduino Uno microcontroller controls the two main functions of the electrical system, which are to identify successful insertion and vary the vein placement between trials. The vein is composed of a Monel wire mesh due to its puncture-friendly characteristics that maintain electrical conductivity, and a copper foil to simulate the posterior wall. The mesh is held at 3V so that when the needle is properly inserted, an LED on the needle will flash. If the user inserts the needle too far, it will hit the copper foil, and the system will indicate that the posterior wall of the vein has been hit. The model can vary vein placement to account for differences between patients, which is done using a switch on the microcontroller. After the user activates the switch, a linear actuator retracts and moves the vein to a new randomized position. The vein is then held in that position for the duration of the insertion. The insertion feedback system can be seen in Figure 4 A), with the visual feedback of the system for a successful insertion being seen in Figure 4 B).

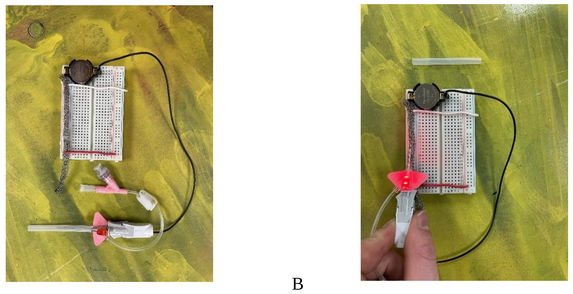


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Figure 3: A) Illustrates the entire electrical system of the simulated vein and IV needle. B) Illustrates when the needle touches the simulated vein, an LED flashback is triggered.

KEY TAKEAWAYS

SUCCESSES
- Anatomically accurate arm model
- Realtime 3D tracking of arm and needle position
- Integrated electrical circuit for insertion feedback

LIMITATIONS
- Webcam tracking using AruCo Markers
- 3D Slicer display
- Arm accuracy

FUTURE WORK
- Improve tracking
- Informative display

References

[1] G. B. Beecham and G. Tackling (2024), *StatPearls.*; [2] R. E. Helm, J. D. Klausner, J. D. Klemperer, L. M. Flint, and E. Huang (2015), *Infus. Nurses Soc, 38.;*