

Robotic System for Central Line Placement

Design Specifications

High-level design specifications:

- **Core functions:** The robot should be able to perform needle insertion, guidewire, and catheter advancement, automating key aspects of central line placement.
- **Patient adaptability:** The robot should be able to adapt to variations in patient anatomy, ensuring compatibility across different individuals and increasing its applicability.
- **Infection mitigation:** The robot should be able to mitigate the risk of infections by incorporating sterilizable components into the system design, enhancing patient safety.
- **Ultrasound integration:** The robot should be able to integrate with a wireless ultrasound probe, facilitating real-time guidance during the procedure.

Low-level design specifications:

- **Angular workspace:** The robot should have an angular workspace of around 10 degrees to 45 degrees relative to the skin, ensuring a suitable range of insertion angles.
- **Degrees of freedom:** The robot should have 2 rotational degrees of freedom and 2 translational degrees of freedom, enabling precise positioning and movement during the procedure.
- **Precision and accuracy:** The robot should have a precision of at least 1mm in all movements with an accuracy of 90%, ensuring reliable and consistent performance.
- **Needle insertion parameters:** The robot should be able to insert an 18-gauge needle at an angle of 30-40 degrees (see [2]) and a depth of 2-6 cm (refer to [3]), conforming to standard central line placement guidelines.
- **Guidewire advancement:** The robot should be able to advance about 10-15 cm of a 50 cm guidewire (see [4]), ensuring proper placement within the target vessel.
- **Guidewire compatibility:** The robot should be able to insert a guidewire with a diameter of 0.035 inches (see [2]) through the needle, accommodating standard guidewire sizes.
- **Catheter compatibility:** The robot should be able to insert a catheter with a size 8.0 French (refer to [2]), conforming to standard central line catheter sizes.
- **Remote center of motion indication:** The robot should be able to indicate the remote center of motion, providing guidance and ensuring proper alignment during the procedure.

Assumptions:

- **Clinician's role:** The clinician will scan the region using ultrasound and decide on the insertion site and angle, ensuring the robot's focus is on the insertion process.
- **Guidewire type:** The guidewire used will be straight without a J-tip, simplifying the design requirements for the guidewire advancement mechanism.
- **No dilators:** Dilators will not be used in the insertion process, reducing the complexity of the robotic system.
- **Manual retraction:** The clinician will manually retract the needle and guidewire, allowing the robot to concentrate on insertion tasks.
- **Detachable syringe:** The syringe will be detachable from the needle without the need for a twisting motion, easing the robot's needle insertion mechanism design.
- **Clinician's assistance:** The clinician will load the guidewire and catheter onto the robot system, simplifying the design requirements for object handling.

References:

1. Suzuki, T., Masahiro Kanazawa, Yoshio Kinefuchi, Haruo Fukuyama, Mamoru Takiguchi, Michio Yamamoto, Kazuhiro Abe, and Yosuke Okuda. "A pilot/introducer needle for central vein cannulation." *The Tokai Journal of Experimental and Clinical Medicine* 20, no. 4-6 (1995): 223-226.
2. Wang, Henry E., and Thomas A. Sweeney. "Subclavian central venous catheterization complicated by guidewire looping and entrapment." *The Journal of emergency medicine* 17, no. 4 (1999): 721-724.
3. Tse, Audrey, and Michael A. Schick. "Central line placement." In *StatPearls [Internet]*. StatPearls Publishing, 2022.
4. Heffner, Alan C., and Amalia Cochran. "Overview of acute and emergency central venous access in adults" in UpToDate, UpToDate Publishing, 2022.