Project Proposal

Team Members and Skills:

- Hangjun Liu: CAD modeling, control system implementation via programming.
- Dihan Liu: arduino control, mathematic model set up
- Chenxi Liu: CAD modeling
- Kaiyu Liu: Virtual environment set up

Topic and Motivation:

Puncture and injection tactile simulation device.

This device simulates haptic feedback of medical procedures related to injections or punctures, especially the sense when the needle punctures the skin, membrane or tissue. It may help to guide the practice of medico or further develop telecommunication which helps to apply remote therapy. Moreover, it may help patients or highschool students to learn about the medical process.

Previous Work:

Towards Telementoring for Needle Insertion

The paper outlines an innovative method to train medical professionals in emergency needle decompression for critical conditions like tension pneumothorax. It introduces a system that lets a mentor feel the force a trainee applies during needle insertion, thus enabling remote instruction.

The experimental framework used a 3D haptic device and a virtual reality interface, allowing mentors to accurately gauge the force applied by trainees, which is vital for successful remote mentoring. The paper suggests enhancements to haptic feedback systems for remote needle procedures and foresees their future clinical use.

This research underscores the significance of haptic feedback in medical training, especially when visual cues are insufficient. These findings are poised to improve training methods, potentially elevating patient care and safety during emergency interventions.

Force Modeling for Needle Insertion Into Soft Tissue

The paper highlights the significance of accurate needle-tissue force modeling to improve surgical simulations, preoperative strategies, and robotic aids in percutaneous therapies. This paper also delves into the forces associated with needle insertion into soft tissues, which is vital for medical tasks like biopsies and injections. Topics of this paper include haptic feedback, tool-tissue dynamics, and force modeling applications in surgery.

The experiments confirm that needle geometry significantly influences insertion dynamics. The authors advocate a mixed empirical-analytical approach for better force understanding and call for further studies with various tissues and in vivo testing for clinical relevance.

This research lays the groundwork for advanced simulations and robotic interventions, aiming to heighten the precision and safety of needle-based medical procedures. It provides comprehensive force models and insights into how needle design affects force dynamics, offering guidance for the development of superior surgical instruments, techniques, and educational platforms for healthcare providers."

Detection of Membrane Puncture with Haptic Feedback using a Tip-Force Sensing Needle

This article describes the creation and evaluation of a novel 3D tip-force sensing needle for minimally invasive surgery, enhanced with haptic feedback. Originating from an MRI-compatible biopsy needle, this device uses fiber Bragg grating (FBG) sensors embedded within to sense strain and deliver instantaneous feedback to the surgeon.

Experiments with participants showed superior accuracy in detecting membrane puncture with the FBG sensor-enhanced needle tip compared to standard feedback methods or none at all. The use of FBG sensors, aside from their accuracy benefits, also brings the advantage of electromagnetic interference immunity, essential for MRI procedures, and the capability for multiplexing to gather data from several sensors along a single fiber. Nonetheless, their temperature sensitivity necessitates additional compensation techniques.

The research comprised calibration, benchtop trials using tissue phantoms, and user testing, all indicating that this enhanced feedback system could significantly aid both novices and experts during needle-based surgeries. Future developments will focus on refining the system and moving towards clinical trials with professional healthcare practitioners.

A haptic force feedback system for teleoperated needle insertion

The study presents a teleoperated needle insertion system designed to minimize doctors' exposure to X-rays during medical procedures. It offers real-time haptic feedback to mirror the resistance typically experienced in manual needle insertions, which could enhance surgical safety and efficiency. The system features a master robot for physician use and a slave robot that executes the insertion, facilitating continuous imaging that may improve accuracy and reduce the duration of the procedures.

The paper describes the mechanical design and control algorithms of a haptic device with 2 degrees of freedom. This device replicates the linear and rotational forces felt during needle insertion, using a novel force control strategy with dual control loops for current and force-tracking, ensuring precise feedback matching.

Tests demonstrate the system's ability to accurately emulate the forces encountered during needle insertion, suggesting substantial improvements in teleoperated surgeries. The paper concludes with an emphasis on further enhancements needed to decrease time lags and refine the control algorithm, thereby improving force feedback's accuracy and timeliness.

Design and Evaluation of Haptic Guidance in Ultrasound-Based Needle-Insertion Procedures

This paper tackles the issue of ultrasound probe alignment during needle insertions, a task that challenges clinicians' spatial and hand-eye coordination skills, often leading to mistakes. The study introduces two haptic feedback systems to aid in stabilizing the probe.

The first system delivers vibrations via a voice coil motor, while the second provides distributed tactile pressure through pneumatics. Both significantly improved control over probe movement and reduced the time taken to correct deviations in benchtop tests. Importantly, the feedback remained noticeable even through a sterile bag and gloves, simulating a clinical environment.

Participants in the study expressed a preference for the pneumatic feedback system. This research underscores the effectiveness of haptic feedback in enhancing performance during ultrasound-guided medical procedures, offering clear benefits for training healthcare professionals. Results presented in this work demonstrates the potential for haptic systems to improve precision and efficiency in medical tasks, and shows promise for elevating both novice and expert capabilities in such procedures.

Real-time Teleoperation of Flexible Beveled-tip Needle Insertion using Haptic Force Feedback and 3D Ultrasound Guidance

This paper investigates a teleoperated system that combines haptic force feedback with 3D ultrasound imaging for improved needle insertions, particularly with flexible beveled-tip needles used in minimally invasive surgeries.

The aim is to enhance the accuracy of needle positioning while reducing tissue damage and the surgeon's mental burden. The system facilitates manual needle control alongside force feedback, allowing the surgeon to feel the needle-tissue interaction. Concurrently, 3D ultrasound offers visual guidance for precise needle navigation.

Experimental results demonstrated a high precision level, with a mean targeting accuracy of 2.5 mm, which meets clinical standards. The study also explores the trade-off between manual operation and automated guidance, testing various autonomy levels from full manual to semi-automatic control. Findings indicate that while automation might enhance safety, it could also limit the operator's ability to make complex, nuanced adjustments.

In conclusion, the research envisions the system's potential to improve surgical outcomes by decreasing the risk of complications from misplacement. Future research directions include testing with more users and incorporating features to automatically adjust for patient movement during procedures.

Proposed Plan:

Our team proposes to design a simulation system that allows medical professionals to practice lumbar punctures. The aim is to create a realistic experience by simulating the texture, hardness and penetration of tissues encountered during lumbar punctures. This novel approach seeks to enhance the tactile feedback during the practice, which is not adequately addressed in current simulation models. The design goal of our team is:

1. The feeling of texture and hardness of the body before the puncture.
2. The feeling of puncturing process. E.g. Blocked by the bone and penetrate the membrane.

Design and Discovery:

- Software: Develop a program that visually represents the practice scenario on a monitor, providing real-time feedback on the needle's position and force applied.
- Hardware: Construct a physical frame with integrated motors and sensors to simulate the x-y-z axis movements of a lumbar puncture. The motors will control the needle's position, while pressure sensors will measure the force exerted by the practitioner. An air pump will simulate tissue resistance, varying the pressure to match the sensation of piercing different tissue densities.

Materials and Resources:

- Software: Software development tools for creating the simulation interface
- Hardware: arduino, frames, motors, pumps, injection syringes and pressure sensors
- Frame structure (mount motors and sensors)
- X-Y axis motors for lateral and longitudinal needle movement
- Pressure sensors and Pump to detect force applied and create air pressure feedback
- Injection syringe modified to work with the system and to simulate injection depth

Checkpoints:

1. Nov. 16
   Concept Validation: Ensure the idea is feasible and try to develop the mathematical model.
   Prototype Design: Develop detailed CAD models of the hardware and a wireframe for the software.
   Material Acquisition: Source the necessary components and materials for construction.
2. Nov. 28
   Assembly and Testing: Build a functional prototype and test its ability to simulate the required tactile feedback.
   Software Integration: Develop and integrate the simulation software with the hardware.

Trial Runs: Conduct trial runs with actual practitioners to gather feedback and refine the system.

3. Dec. 10
   Final Review: Evaluate the simulation's effectiveness and make any necessary adjustments.