Lit-review: Research Proposal

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Previous Research

Human Arm Pose Estimation and Mimicry using Franka Emika Panda

Goal: Develop a real-time system where the Franka Emika Panda robot mimics human arm motion using <u>2D pose estimation</u> and trajectory planning.

Methods:

1) <u>Pose Estimation:</u> Extracted 2D upper-limb keypoints (shoulder, elbow, wrist) using OpenPose + Intel RealSense D415.

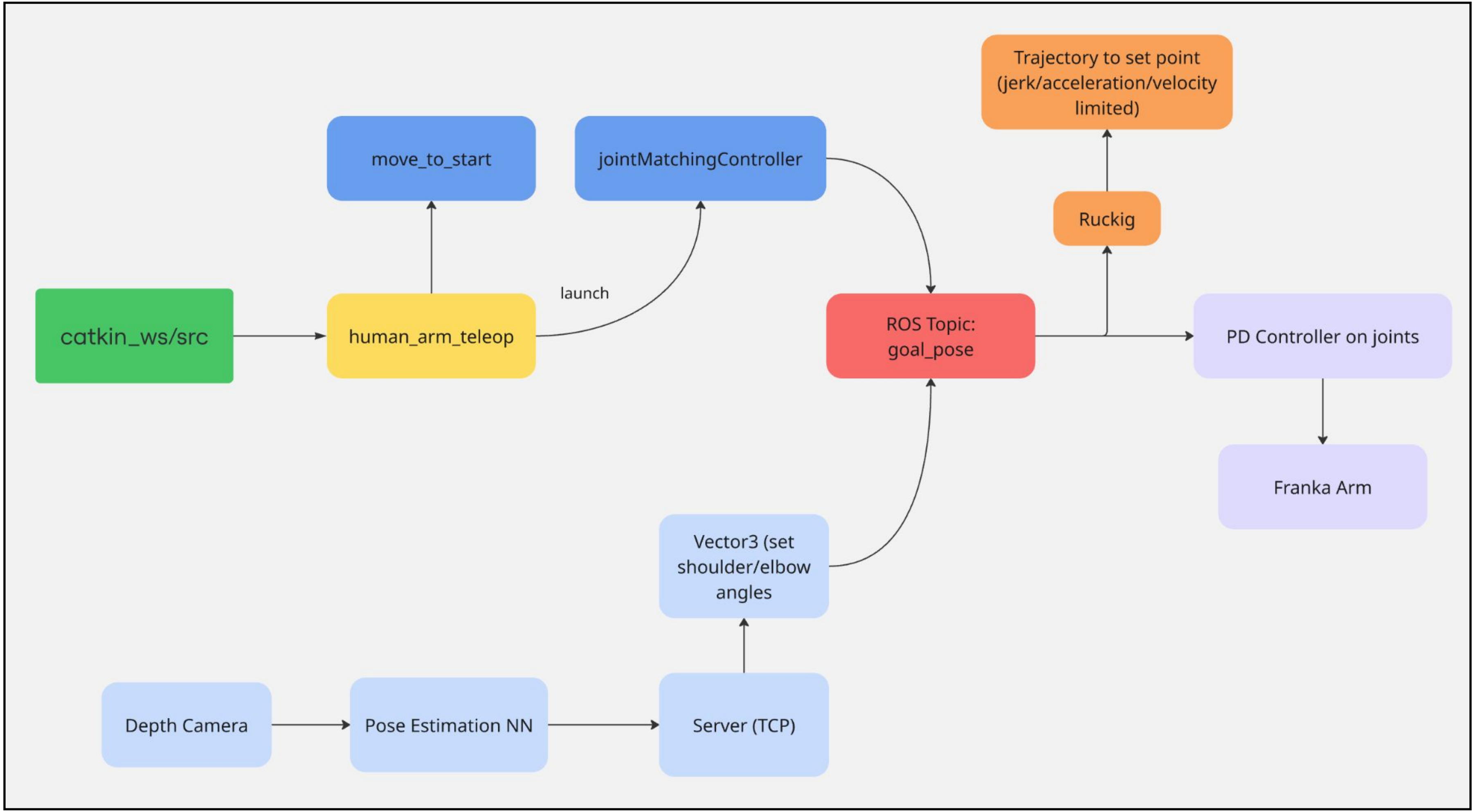
2) <u>Joint Angle Computation:</u> Estimated joint angles (shoulder, elbow) from keypoints.

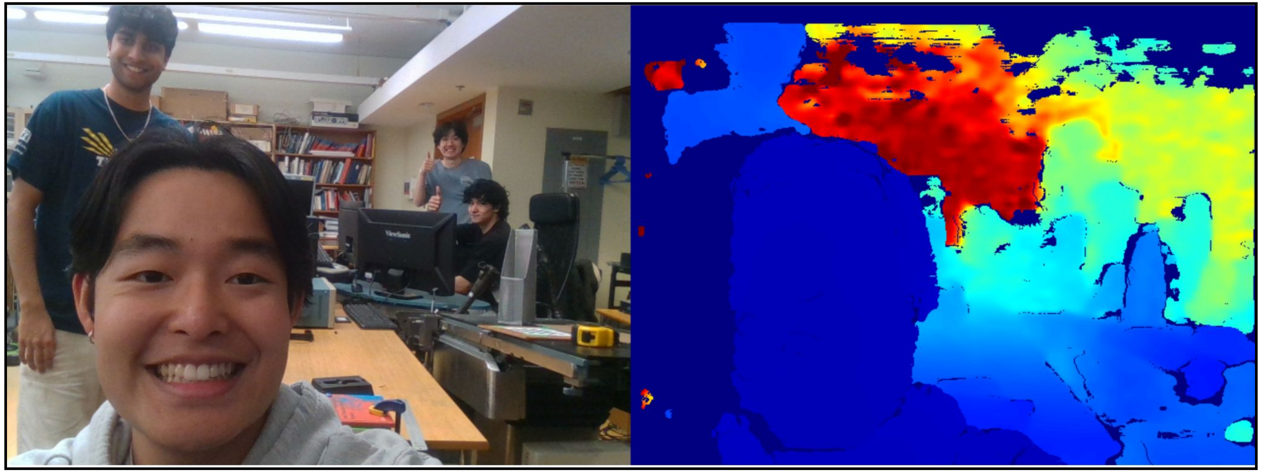
3) <u>Communication:</u> Transmitted angles via custom TCP to a ROS1-based control stack.

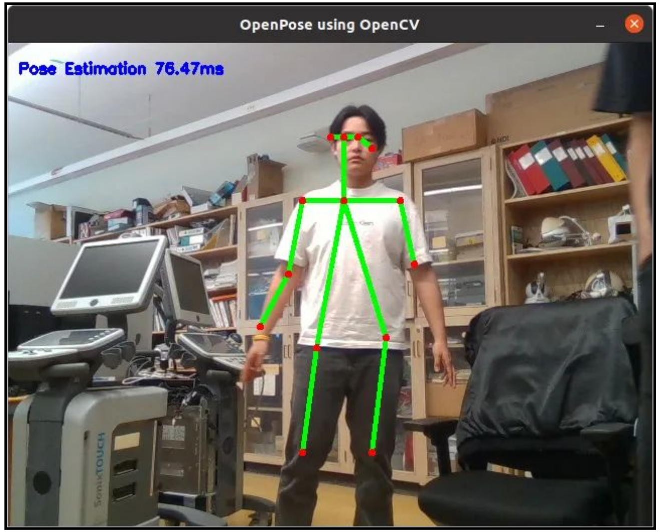
4) <u>Robot Control:</u> Used PD control and Ruckig trajectory generation for smooth mimicry.

Limitations and Improvements:

- 2D estimation lacks depth, resulting in lower spatial accuracy.
- No feedback loop or evaluation of motion quality with reinforcement learning.


Trajectory to set point (jerk/acceleration/velocity limited)
move_to_start
jointMatchingController
Ruckig
launch
catkin_ws/src
human_arm_teleop
ROS Topic: goal_pose
PD Controller on joints
Franka Arm
Vector3 (set shoulder/elbow angles
Depth Camera
Pose Estimation NN
Server (TCP)




OpenPose using OpenCV
Pose Estimation 76.47ms

Proposal 1

AI-Guided Robotic Rehabilitation & Mirror Therapy Using 3D Pose Estimation with Franka Emika

Problem:

- Stroke and neurodegenerative diseases impair motor control.
- Traditional physiotherapy is repetitive, hard to access, and resource-heavy.

Opportunity:

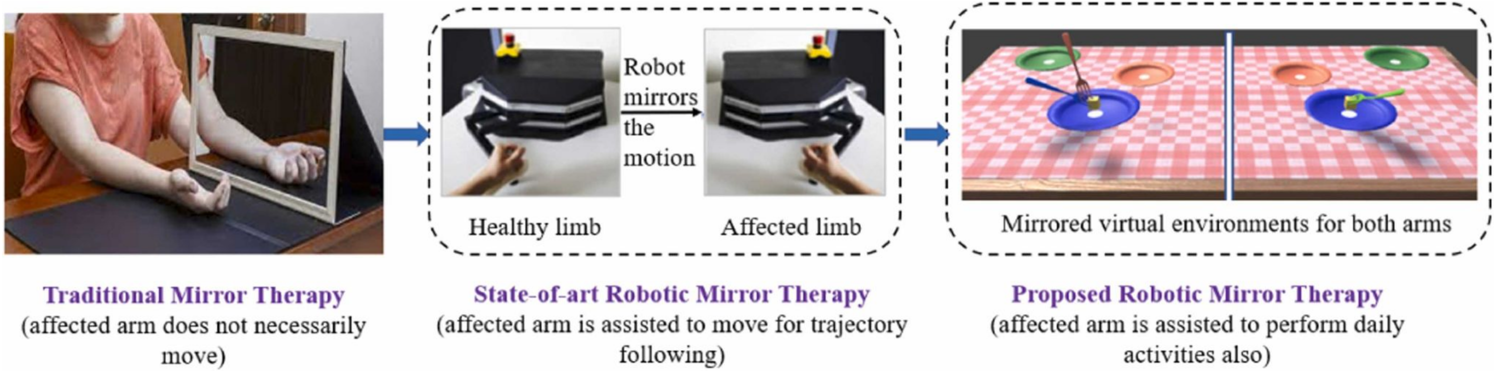
- Robotic rehabilitation is scalable and effective, especially for rural or aging populations.

Vision:

- Use 3D vision + AI/ML + Franka Emika to deliver intelligent, low-cost, and personalized rehab therapy.

Objectives:

- Track human upper-limb movement (shoulder, elbow, wrist) in 3D
- Control Franka Emika for safe, adaptive rehab interactions
- Implementations:
    - *Rehabilitation Assistant* (motion guidance + feedback)
    - *Mirror Therapy System* (healthy limb mirrored to impaired side usually after a stroke)



[How effective is mirror therapy?]

Proposal 1

AI-Guided Robotic Rehabilitation & Mirror Therapy Using 3D Pose Estimation with Franka Emika

Goal: explore how low-cost robotics and AI can support rehabilitation, especially for underserved populations, and measure its impact

Link Previous Research to Current Proposal:

- Expanding from 2D → 3D pose estimation
- Adding Cartesian impedance control for safer interaction
- Introducing mirror therapy and AI feedback
- Building a complete rehabilitation system

<u>3D Pose Estimation:</u> Intel RealSense + OpenPose 3D + Kalman Filter

<u>Kinematic Mapping:</u> Joint angle computation → IK → libfranka (Ruckig)

<u>Control Strategy:</u> Cartesian Impedance Control for compliance

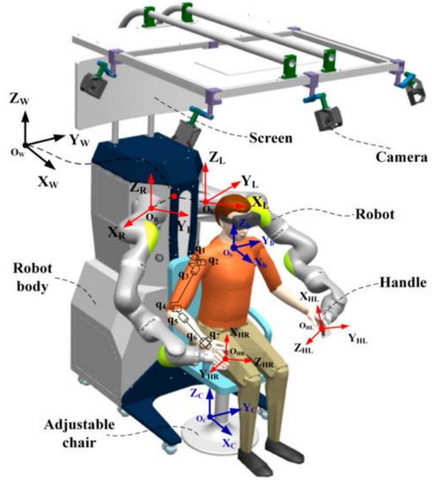
<u>Core Deliverables:</u> **Hardware:** Franka Emika Panda, Intel RealSense D435. **Software:** OpenPose 3D or MediaPipe Holistic, ROS2 + libfranka, Python, MATLAB

Research Paper 1 Review

Development and Assist-As-Needed Control of an End-Effector Upper Limb Rehabilitation Robot

by Leigang Zhang *, Shuai Guo * and Qing Sun

- End-Effector Upper Limb Rehabilitation Robot **(EULRR)**
- Provides **Assist-As-Needed (AAN)** support for patients with upper limb motor dysfunction
- Offers freedom of movement while guiding them to follow a rehabilitation path

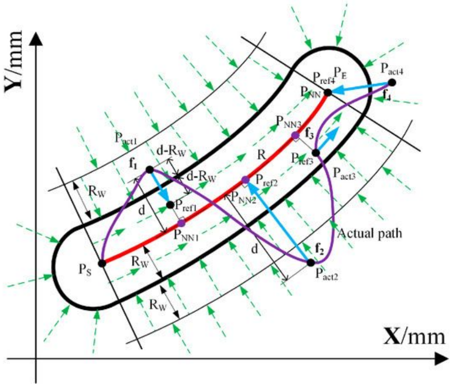


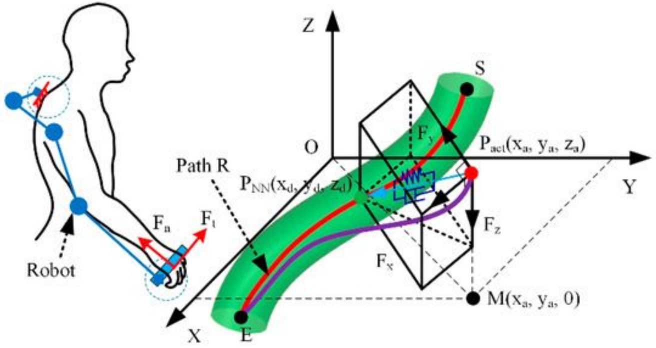
- A dual-arm robot using 7-DOF manipulators
- Three-dimensional spatial rehabilitation
- Based on Cartesian impedance control
- The robot can **assist patients only when needed**, enhancing engagement and neuroplasticity

https://www.mdpi.com/2076-3417/10/19/6684

(a) (b)

Research Paper 1 Continue





- Implements a **virtual channel** (tunnel) around a desired trajectory
- Make the robot fully compliant when the patient is moving along the planned trajectory inside the virtual channel
- or
- alternatively, stiffer when the patient is moving out of the virtual channel.

Limitations & Future Work of the Research

- Only one healthy subject was tested.
- **Unity-based visual interface** was basic.
- Plans include testing with elderly patients and stroke survivors, improving handle design, and enhancing the **VR training environment**.
- External Motion Validation (Human Arm Pose Estimation):
- **Track elbow, wrist, and shoulder** joint positions for a more complete understanding of upper limb biomechanics during rehab

Research Paper 2 Review

Comparisons between end-effector and exoskeleton rehabilitation robots regarding upper extremity function among chronic stroke patients with moderate-to-severe upper limb impairment

Stephanie Hyeyoung Lee, Gyulee Park, Duk Youn Cho, Ha Yeon Kim, Ji-Yeong Lee, Suyoung Kim, Si-Bog Park & Joon-Ho Shin

- After 4 weeks of robotic training, **end-effector robots led to greater improvements in activity Wolf Motor Function Test (WMFT) and Stroke Impact Scale (SIS) participation domain** than exoskeleton robots among chronic stroke patients with moderate-to-severe upper limb impairment—with no safety concerns (Nature S.H. Lee et. al.)
- **Exoskeleton Robot**
- **Pros:** Could provide direct assistance and recovery evaluation at each human joint.
- **Cons:** Has complex anatomical structure of human upper limbs - leads to additional interactive forces and torques between the exoskeleton robot and human upper limbs during the rehabilitation training.
- **End-effector Robot**
- **Pros:** Has a simpler structure and could adapt to different patients better - research shows that it has good effectiveness in the rehabilitation training of upper limb motor function and daily activities compared with the traditional rehabilitation methods.
- **Cons:** However, most of the existing end-effector-based upper limb rehabilitation robots can only carry out training tasks in a specific plane, which cannot satisfy the requirements of rehabilitation training in three-dimensional space within the human arm's workspace.

Proposal 2

Teleoperated Robotic Ultrasound Imaging System Using Franka Emika for Remote Diagnostic Scanning

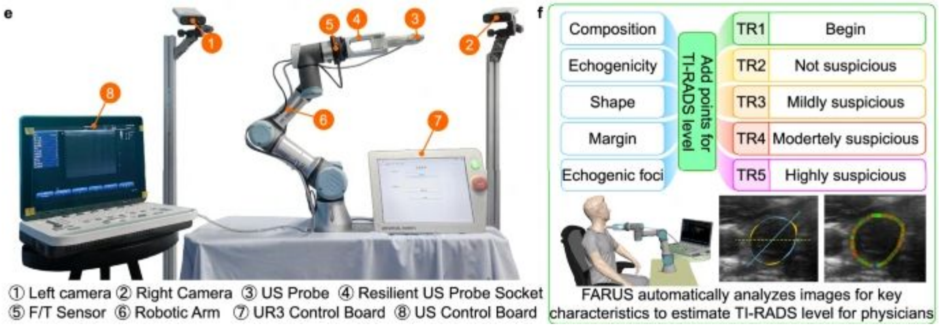
Goal: Use robotic teleoperation and force feedback to allow expert sonographers to perform remote ultrasound scans—especially in underserved or isolated areas

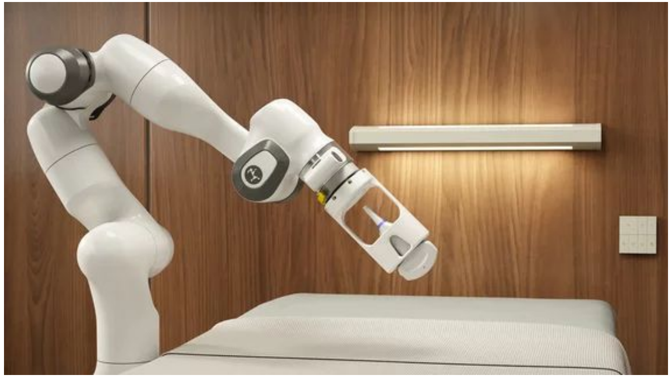
Objectives:

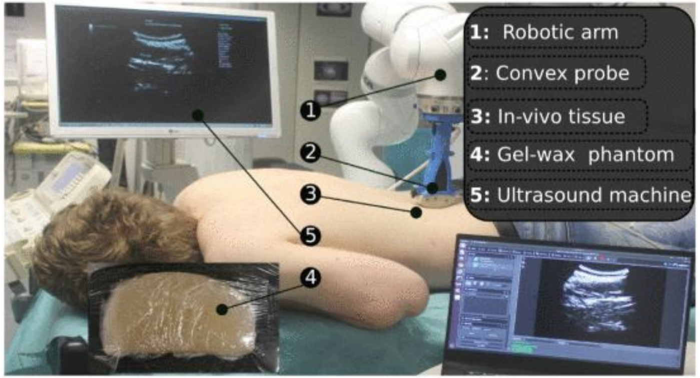
- Enable remote probe control with Franka Emika.
- Ensure safe contact via real-time force feedback.
- Use Intel RealSense for 3D modeling and planning.
- Stream ultrasound and robot feedback to remote expert.
- Integrate Touch Haptic Device for immersive control.

Control Strategies

1) *Teleoperation* – operator controls probe directly, with force-threshold-based safety (admittance/impedance).
2) *Shared Control* – operator controls direction; robot maintains contact force and orientation automatically.


e
f
Composition
Echogenicity
Shape
Margin
Echogenic foci
Add points for TI-RADS level
TR1 Begin
TR2 Not suspicious
TR3 Mildly suspicious
TR4 Modertely suspicious
TR5 Highly suspicious
① Left camera ② Right Camera ③ US Probe ④ Resilient US Probe Socket
⑤ F/T Sensor ⑥ Robotic Arm ⑦ UR3 Control Board ⑧ US Control Board
FARUS automatically analyzes images for key characteristics to estimate TI-RADS level for physicians




1: Robotic arm
2: Convex probe
3: In-vivo tissue
4: Gel-wax phantom
5: Ultrasound machine

Proposal 2

Teleoperated Robotic Ultrasound Imaging System Using Franka Emika for Remote Diagnostic Scanning

Resources Needed:

1) *Franka Emika:* Force-compliant robotic control
2) *RealSense D435:* 3D surface modeling
3) *Touch Haptic or Joystick*: Master teleop interface
4) *Ultrasound Probe:* Imaging device (e.g., Clarius)
5) *Gel Phantom:* Safe test medium
6) *PC + ROS*: Real-time communication and control

Project Scope & Milestones

- Franka + RealSense + joystick control setup
- Implement force-limited admittance control
- Integrate ultrasound probe + stream images
- Run trials on phantom/gel pads
- Extra: Add AI/image feedback or visual servoing

Research Paper 1 Review

A fully autonomous robotic ultrasound system for thyroid scanning

Kang Su, Jingwei Liu, Xiaoqi Ren, Yingxiang Huo, Guanglong Du ✉, Wei Zhao, Xueqian Wang ✉, Bin Liang ✉, Di Li & Peter Xiaoping Liu ✉

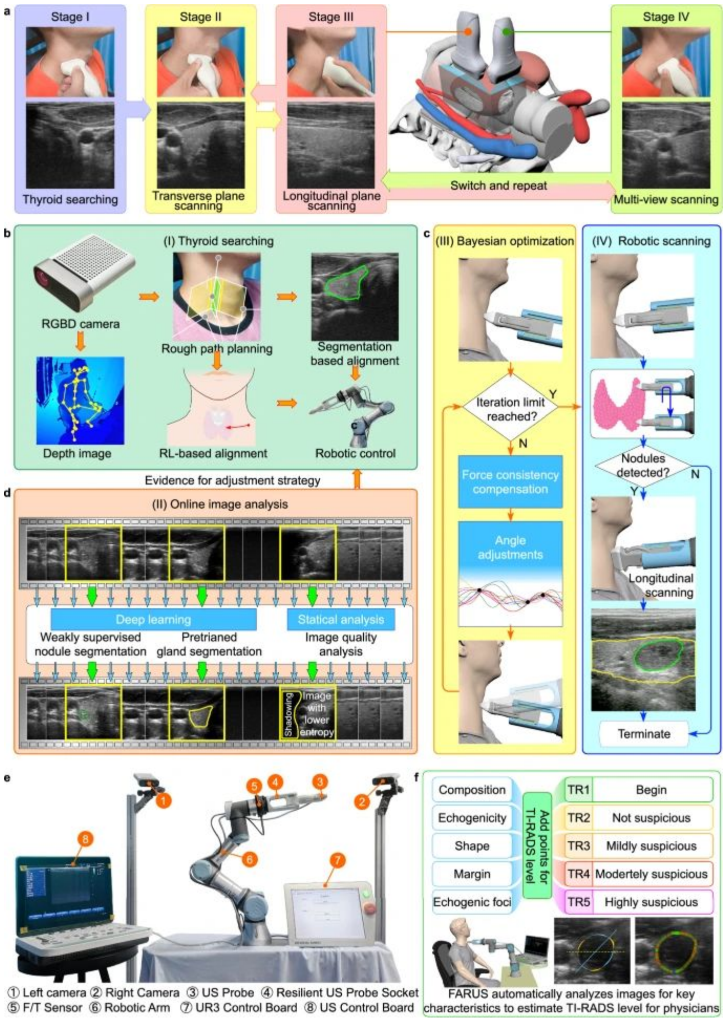
FARUS (Fully Autonomous Robotic Ultrasound System) integrates:

- A 6-axis UR3 robotic arm holding a linear ultrasound probe.
- A Kinect camera for recognizing human skeletal orientation.
- Force/torque feedback mechanisms for safe, adaptive pressure control.
- Algorithms utilizing reinforcement learning, Bayesian optimization, and real-time deep learning-based thyroid segmentation

Technical Approach

1. **Initial Positioning** (IPS): Uses skeletal detection and Bayesian optimization to orient the probe.

2. **Optimal Scanning**: Dynamic control of probe position and applied force, ensuring capture of diagnostic-quality images



References

Proposal 1:

https://healthcare-in-europe.com/en/news/meet-robert-your-robotic-physio-therapist.html
https://www.sciencedirect.com/science/article/pii/S2001037024000175
https://www.youtube.com/watch?v=XSaUNIEsrnM&ab_channel=TUTMechanicalEngineeringandIndustrialSystems
https://www.sciencedirect.com/science/article/pii/S2001037024000175
https://pmc.ncbi.nlm.nih.gov/articles/PMC6513639/#:~:text=Mirror%20therapy%20(MT)%20is%20a,sensation%2C%20and%20pain%20are%20stimulated

https://www.nature.com/articles/s41598-020-58630-2#Sec12

https://link.springer.com/article/10.1007/s42454-023-00048-y#Sec69

https://www.physio-pedia.com/Wolf_Motor_Function_Test_(WMFT)

https://www.meta.com/experiences/vrmt/5954556421337276/?srsltid=AfmBOooSLXBkyZSejHuqIMaflDZ9qre9AV3JZntFnc1ajKYsfeJUJ2qS

References

Proposal 2:

https://nvidianews.nvidia.com/news/nvidia-and-ge-healthcare-collaborate-to-advance-the-development-of-autonomous-diagnostic-imaging-with-physical-ai

https://www.nature.com/articles/s41467-024-48421-y

https://ieeexplore.ieee.org/abstract/document/9756910

https://www.sciencedirect.com/science/article/pii/S1746809421004973

https://www.sciencedirect.com/science/article/pii/S136184152300138X

https://www.nature.com/articles/s41467-025-62865-w#Sec2