# Robotic Mirror Therapy for Stroke Rehabilitation through Virtual Activities of Daily Living


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ISE 100 YEARS

## Purpose

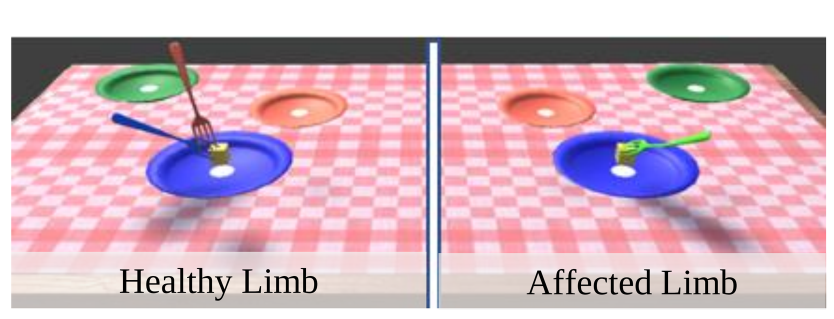
- Each year, 12.2 million new strokes occur and one in four people over the age of 25 will have a stroke in their lifetime.
- The high morbidity level of stroke leaves countless people disabled and in the need of specialized medical care.
- Ischemic stroke (87% of strokes) can lead to partial (hemiparesis) or complete (hemiplegic) paralysis of one limb.
- This motor impairment reduces motor function in stroke patients.
- Reduced motor function greatly reduces their ability to complete activities of daily living (ADL).
- There is a strong correlation between ADL performance and a quality of life.

## Current State of Therapy Delivery

- Mirror therapy is commonly used by therapists to recover motor function in hemiparetic patients.
- Patients make coordinated bilateral movements, either physically or through the illusion of a mirror.
- Robots have also been explored to automate therapy delivery.
- These robotic systems do not typically cater to daily life task-oriented training.

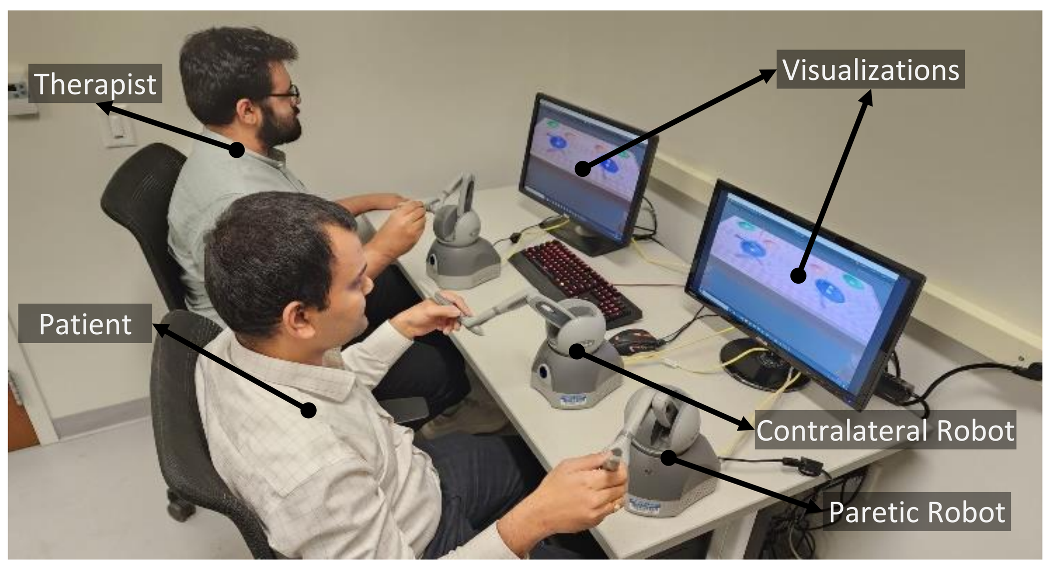
## Our Proposed Approach


Traditional Mirror Therapy | Robotic Mirror Therapy

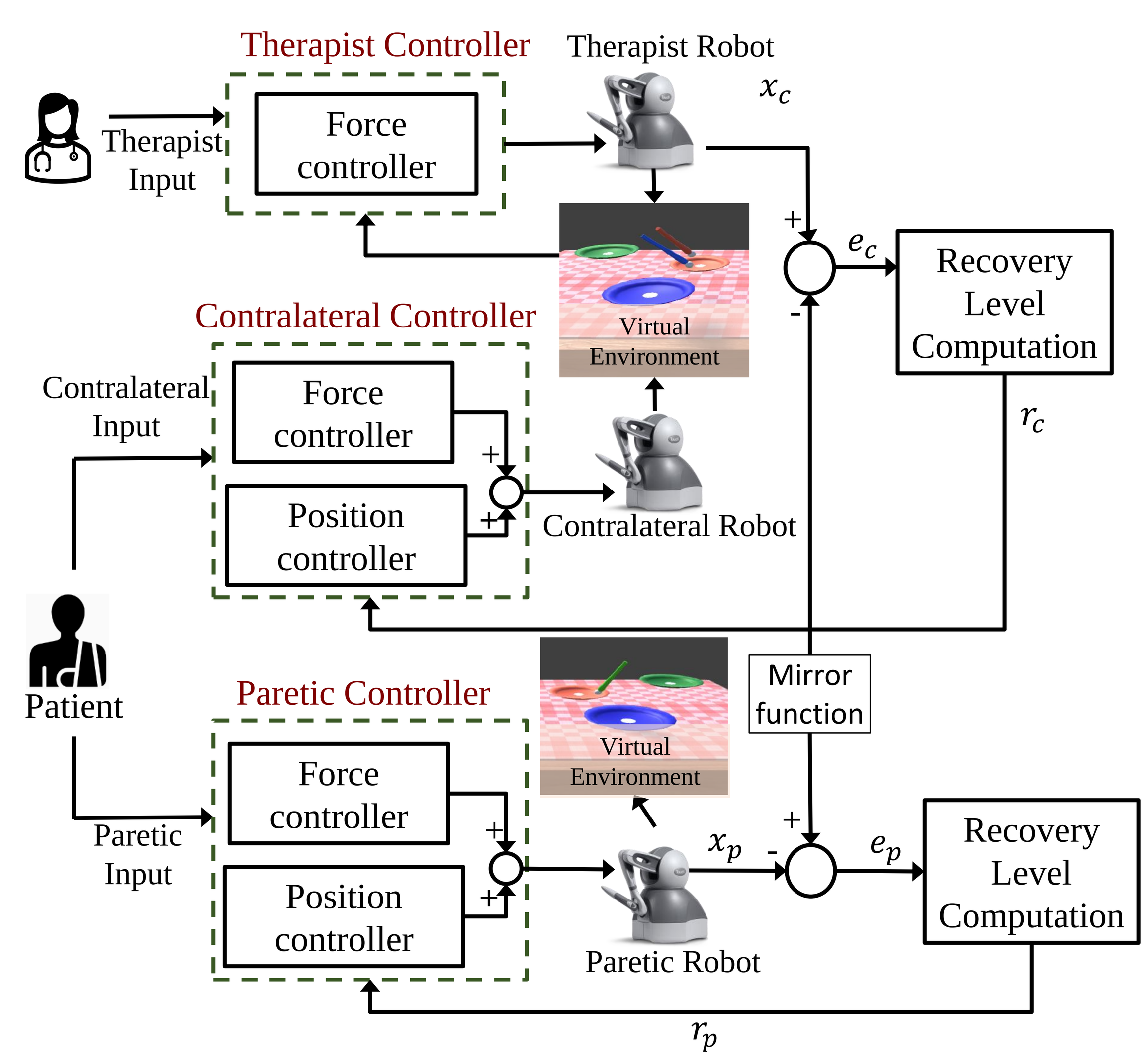



Proposed Robotic Mirror Therapy

- In our proposed RMT framework, the patient operates two physical robots with their upper limbs in two mirrored virtual environments.
- These virtual environments are visualized by the participants on a monitor.
- Throughout the session, the therapist can lead the patient's contralateral limb.
- The mirror of the patient's contralateral limb leads the patient's paretic limb.
- A recovery level that is inversely proportional to the position error between each of the patient's limbs and its leader is calculated.
- An assistive force is provided to the patient's limbs through their corresponding robots scaled by the limb's recovery level.
- All three limbs experience complete force feedback from the virtual environment which allows for the creation of realistic simulations of ADL.




## Framework Architecture




## Features: Recovery Level

- Error between the therapist and patient's contralateral limb, $\hat{e}_c(t)$, is calculated as $\hat{e}_c(t) = f(x_{th}(t), x_c(t))$.
- $f: (R^3, R^3) \rightarrow R$ is the error function (Euclidean distance here), $x_{th}(t) \in R^3$ is the 3D Cartesian coordinates of the end-effector controlled by the therapist, and $x_c(t) \in R^3$is the position of the of the end-effector controlled by the contralateral limb of the patient.
- Then, $r_c(t) = 1 - \frac{\hat{e}_c(t)}{e_0}$ where $e_0$ is the maximum possible error
- Recovery level for paretic limb, $r_p(t)$, is found similarly besides that the error, $\hat{e}_p(t)$, is taken between the mirrored contralateral limb position, $\tilde{x}_c(t)$, and the paretic limb position, $x_p(t)$.
- A weighted average between both $r_c(t)$ and $r_p(t)$ is computed as the overall recovery level of the patient as follows: $r(t) = \alpha \cdot r_c(t) + \beta \cdot r_p(t)$ where $\alpha$ and $\beta$ are scalars determined by the therapist per patient.

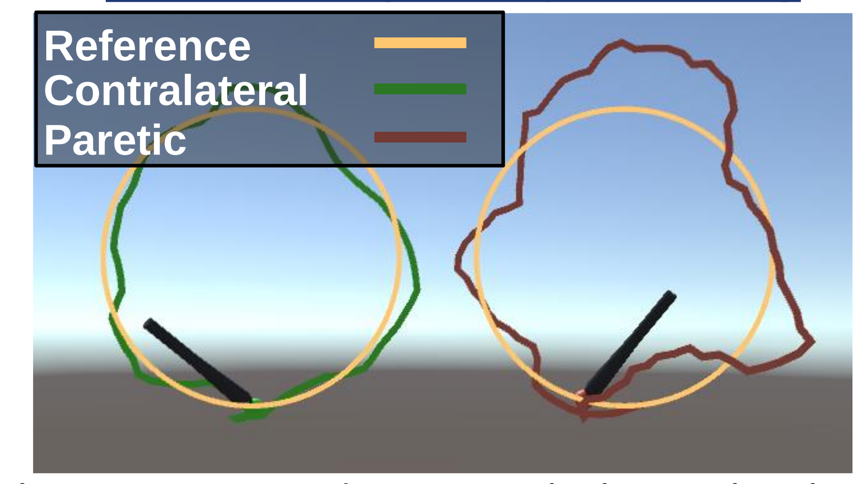
## Features: Adaptive Assistance Level

- An adaptive assistance is provided to both the patient's limbs through the robots to assist them in tracking their corresponding leader.
- The direction of this assistance is determined by the normalized vector formed between the therapist and the contralateral limb.
- The magnitude is determined to be $\gamma \cdot (1 - r_c(t))$, where $\gamma$ is a constant scaling factor, in Newtons, which is decided by the therapist for each specific patient.
- A similar computation is done for the paretic limb with a different scaling factor ($\sigma$).

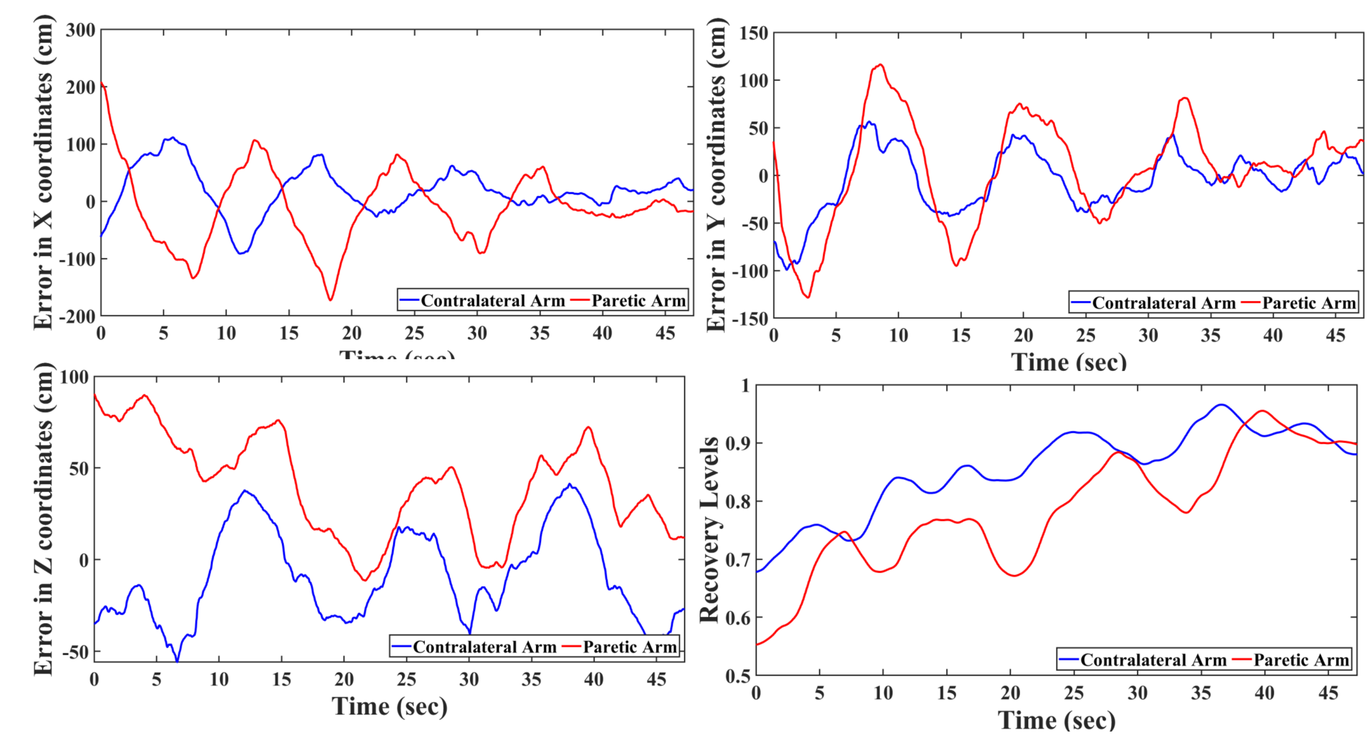
## Features: Complete Force Feedback

- The therapist and patient can navigate virtual environments with their robots.
- While interacting with objects in virtual environments, the robots are programmed to supply feedback forces from the objects in the environments.
- This enables both the therapist and patient to perceive the environment accurately

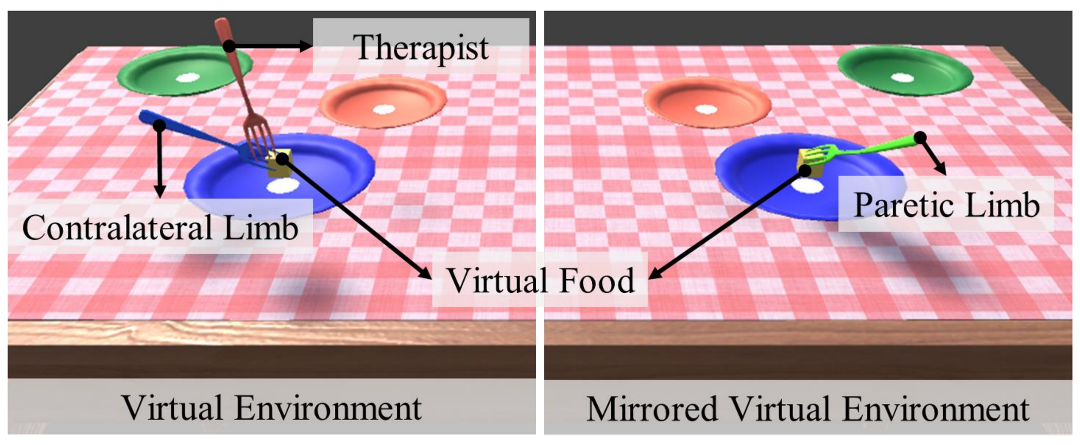
## Task 1: Trajectory Tracking




- The therapist can draw symbols with their robot or predefined trajectories can also be use.
- The patient must track the therapist or predefined trajectory.
- A healthy subject simulated the patient and is asked to follow the 3D trajectories with both limbs.

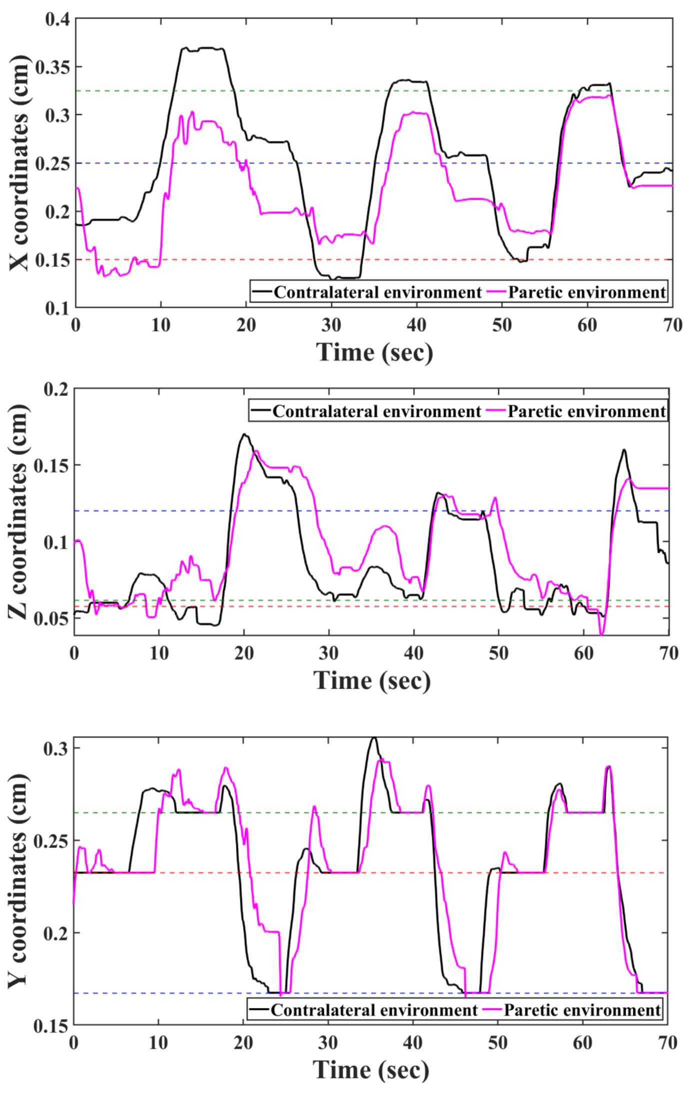



## Task 1: ADL Practice (Pick & Place)

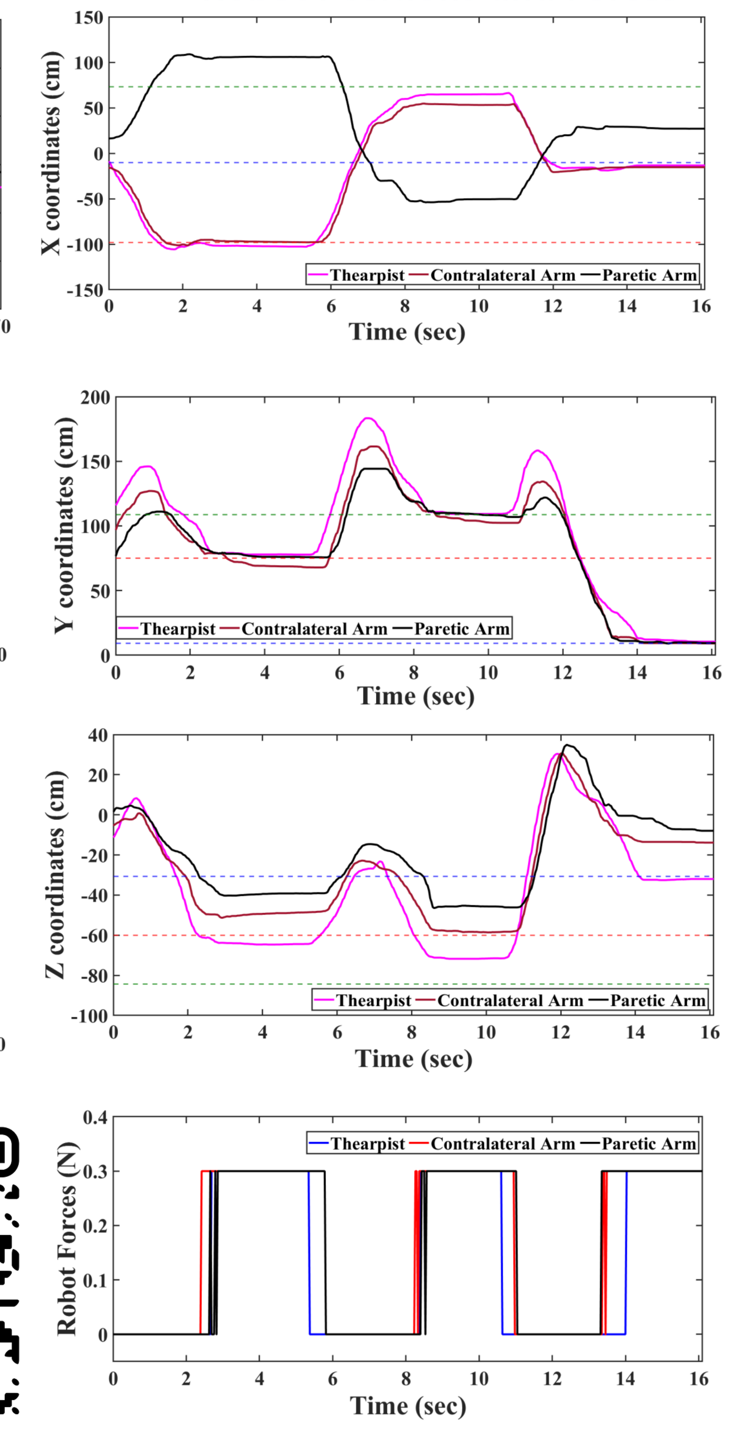



- Two virtual dining room environments are created. One is the mirror of the other.
- The therapist leads the contralateral limb to pick up virtual food from one plate and place it on another. The paretic limb must complete the same task but mirrored in the mirrored environment.

*Food Trajectories*




*Robot Positions and Forces*




*Paper* | *Demo Video*