Robotics & Intelligent Systems Expo (RISEx 2025), Nov. 13-14, 2025, Edmonton, Canada

ADAPTIVE ASSISTIVE ADMITTANCE CONTROL FOR ROBOTIC UPPER LIMB REHABILITATION

Mohammad Farajtabar[1] and Marie Charbonneau[1]
[1] Department of Mechanical and Manufacturing Engineering, University of Calgary, Calgary, Canada.
Email: mohammad.farajtabar@ucalgary.ca

INTRODUCTION

Advances in robotics and AI are making robots integral to daily life, highlighting the importance of studying Human-Robot Interaction. In healthcare, particularly rehabilitation, robots can serve as reliable assistants [1]. We propose an assistive variable admittance control method for upper limb rehabilitation [2], where users guide the robot's end effector (EE) along a desired path. An adaptation rule supports motion, and an assistance mode aids when the interaction force deviates from the trajectory, while passivity analysis [3] ensures stability.

MATERIALS AND METHODS

The Cartesian admittance model, which relates the EE force to its linear motion when the robot follows user guidance without a reference trajectory, is given by:

$$\boldsymbol{M}_a\ddot{\boldsymbol{X}}_e + \boldsymbol{C}_a\dot{\boldsymbol{X}}_e = \boldsymbol{F}_{ext}, \qquad (1)$$

where $\dot{\boldsymbol{X}}_e$ and $\ddot{\boldsymbol{X}}_e \in \mathbb{R}^3$ are the velocity and acceleration responses to the external force $\boldsymbol{F}_{ext}$, and $\boldsymbol{M}_a$, $\boldsymbol{C}_a$, and $\boldsymbol{K}_a \in \mathbb{R}^{3\times3}$ are the diagonal admittance mass, damping, and stiffness matrices. Here, we propose an admittance parameter adaptation rule to support human motion based on the interaction force at the EE:

$$C_a = \frac{F_{std}}{\|\dot{\boldsymbol{X}}_e\|}\left(1 + \frac{\beta}{1 + ue^{-\nu A}}\right), \qquad (2)$$

$$M_a = M_0\left(1 + \epsilon\|\ddot{\boldsymbol{X}}_e\| + \frac{\gamma}{1+ue^{-\nu A}}\right), \text{ if } \|\ddot{\boldsymbol{X}}_e\| > \ddot{X}_{max} \qquad (3)$$

where

$$A = 1 - \frac{\boldsymbol{F}_{ext}.(\boldsymbol{X_d} - \boldsymbol{X_e})}{\|\boldsymbol{F}_{ext}\|\|\boldsymbol{X_d} - \boldsymbol{X_e}\|} \qquad (4)$$

and $\beta, \gamma, \epsilon, u$, and ν are positive constants, $\boldsymbol{M}_a = M_a\boldsymbol{I}$ and $\boldsymbol{C}_a = C_a\boldsymbol{I}$. The term A, in fact, is $1 - \cos\alpha$, where α is the angle between the applied force and the vector from the EE to the nearest next waypoint on a given trajectory. The adaptation rule promotes force alignment with the trajectory: it increases damping and mass when $\boldsymbol{F}_{ext}$ deviates from the intended direction, reduces damping as $\boldsymbol{F}_{ext}$ magnitude grows, and raises mass at high accelerations to stabilize motion. To ensure stability, restrictions on M_a and C_a, along with the passivity condition $\dot{M}_a \leq 2\mu C_a$ (with $0 < \mu < 1$), are imposed. With adaptation rules supporting the user to track a trajectory, we introduce an assistive mode for cases where force misalignment A exceeds a threshold σ, as adaptation alone cannot ensure correct force application. When $A > \sigma$ and the EE position deviates from the target trajectory beyond a predefined error X_{wall}, the joint velocity input to the controller is:

$$\dot{\boldsymbol{q}}_f = \dot{\boldsymbol{q}}_{ad} + \dot{\boldsymbol{q}}_{assist}, \qquad (6)$$

where $\dot{\boldsymbol{q}}_{ad}$ is the velocity from admittance control (via inverse kinematics), $\dot{\boldsymbol{q}}_{assist}$ is the assistive velocity, and $\dot{\boldsymbol{q}}_f$ is the final command to the controller. The assistive command is obtained by solving an optimization problem, with the cost function minimized over $\dot{\boldsymbol{q}}_{assist}$:

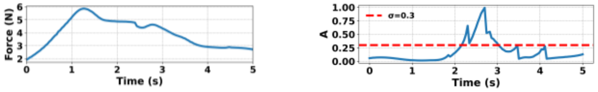
$$\left\|J(\dot{\boldsymbol{q}}_{ad} + \dot{\boldsymbol{q}}_{assist}) - \dot{\boldsymbol{X}}_r\right\|^2 + \lambda\|\dot{\boldsymbol{q}}_{ad} + \dot{\boldsymbol{q}}_{assist}\| \qquad (7)$$

here, $J \in \mathbb{R}^{3\times n}$ is the robot's Jacobian, and $\dot{\boldsymbol{X}}_r = k_p(\boldsymbol{X_d} - \boldsymbol{X_e})$ is the desired EE velocity toward the target, with $k_p > 0$ as a proportional gain.

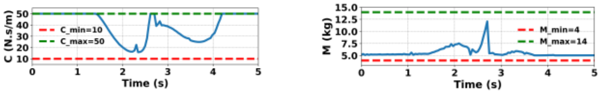
RESULTS AND DISCUSSION

The method is validated on a Kinova Gen3 arm. Figs. 1a-c illustrate the rehabilitation exercise, the physical robot setup, and the desired trajectory with assistance (blue), along with the final EE velocities (purple) and interaction force (yellow). Fig. 1d shows the magnitude of $\boldsymbol{F}_{ext}$, while Fig. 1e depicts the force deviation A. In Fig. 1f, as $\boldsymbol{F}_{ext}$ increases (time 1.5-2.3s), damping C_a decreases to ease motion and raise EE velocity. When the $\boldsymbol{F}_{ext}$ deviation from the trajectory increases (time 2.3-2.6s), C_a increases to limit velocity. Fig. 1g highlights the adaptation effect on inertia M_a, and Fig. 1h demonstrates how adaptive admittance regulates EE velocity. Finally, Fig. 1i shows that assistance reduces trajectory tracking error compared to fixed admittance (with no assistance).

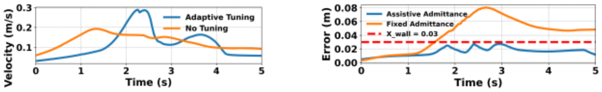
a) Rehabilitation exercise b) Physical robot experiment c) EE velocity demonstration



d) Interaction force magnitude e) Change of A



f) Adaptive change of C g) Adaptive change of M



h) Effect of adaptation on admittance velocity i) Effect of assistance on the trajectory error

Fig 1 Performance of the proposed assistive admittance controller.

CONCLUSIONS

We proposed an adaptive assistive admittance driven by interaction force control to support upper-limb rehabilitation exercises. The method reduces trajectory tracking errors while providing reliable guidance. Future work will explore learning-based approaches for more natural adaptation to human intention.

REFERENCES

[1] Farajtabar M et al. *Robot. & Aut. Sys.*: 104829, 2024.
[2] Wu Q et al. *Mechatronics*, **90**:102935, 2023.
[3] Sharifi M et al. *IEEE Trans. on Cyber*. **52(7)**: 6462–6475, 2022