

Networked and Collaborative Robots for Healthcare and Industry

Dr. Hamid Sadeghian

Munich Institute of Robotics and Machine Intelligence

Technical University of Munich

Feb. 2026



TUM Leader in Academic Rankings

(Statistics 2025)



#22

UNIVERSITY

QS World University Rankings 2025

#1

UNIVERSITY

THE - Times Higher Education World University
Rankings 2025 in Germany

TUM MIRMI Facts and Figures

(Statistics 2025)

22

ERC Grants

4

Leibniz Prizes

2

Humboldt
Professorships

200+

Senior
Scientists and
Postdocs with
MIRMI PIs

110

Chairs
Connected with MIRMI
in
7 TUM Schools

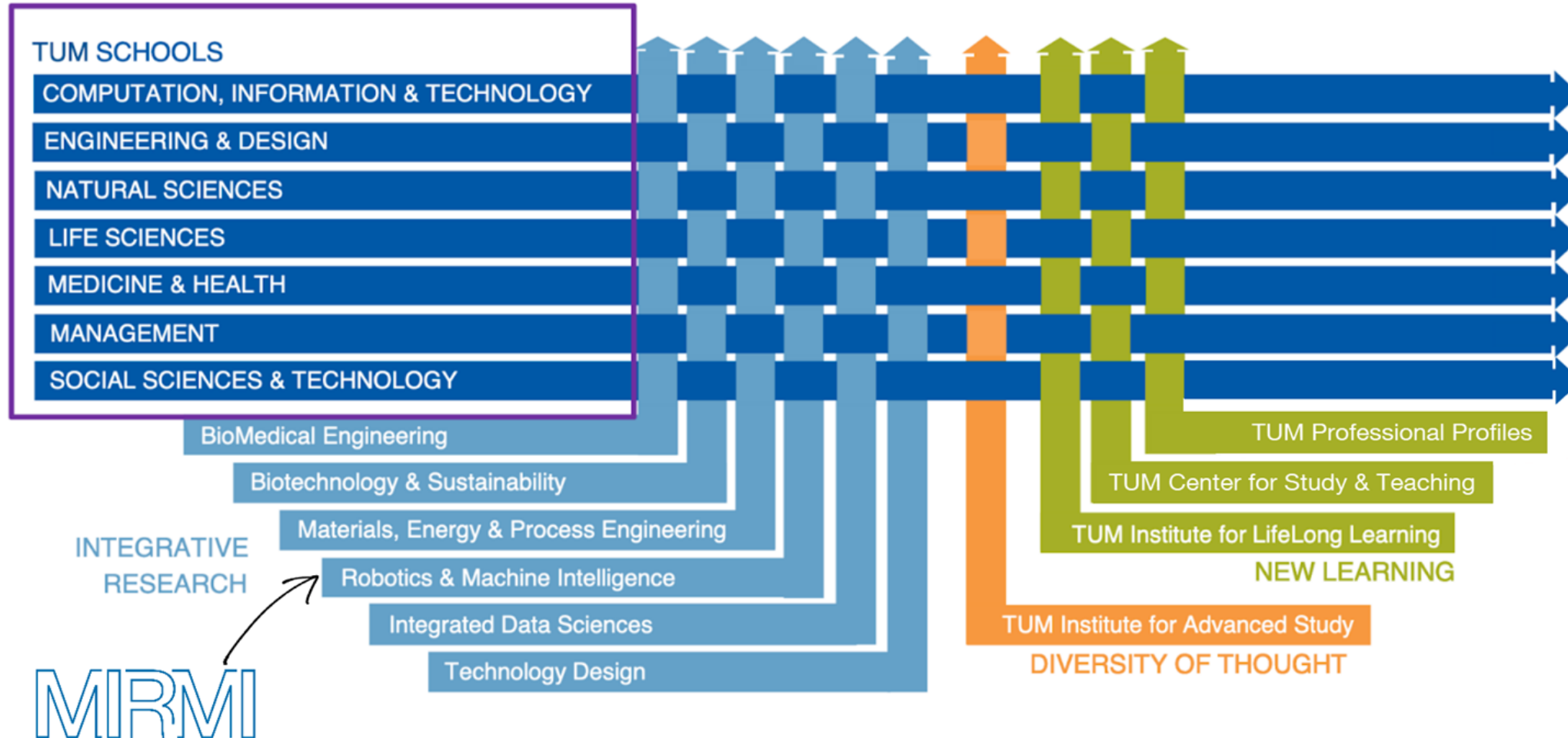
50+

TUM Innovations
on the EU's
Innovation Radar

1.000+

PhDs
Supervised by
MIRMI PIs

MIRMI in TUM





GBR - Georg-Brauchle-Ring



TUM/DHM - Digital OR



(MUC) Munich Urban Colab



HEß - MIRMI Headquarters



MRI - Medical Robotics Center



DM - Deutsches Museum

ELI - TUM Center for
Embodied Laboratory
IntelligenceSTC - Siemens Technology
Center

CZS - Carl-Zeiss-Str.



PARK - Parking



GAP - Geriatrics Center



TUM/GAP - TUM Campus

Running

Build Up

Planning

Projects Highlights

Research Success Stories

TUM Campus Geriatrik

Maintain mobility and independence for seniors with Geriatrics robotic assistance systems



6G-Life

Future 6G networks with a focus on human-machine collaboration

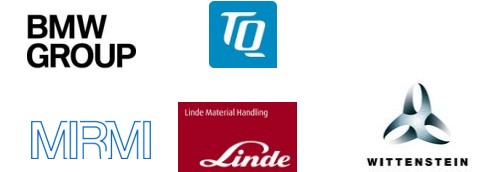


5 EU projects: Reconcycle, Illiad, Eu Robin, Darko...



KI.FABRIK Bayern

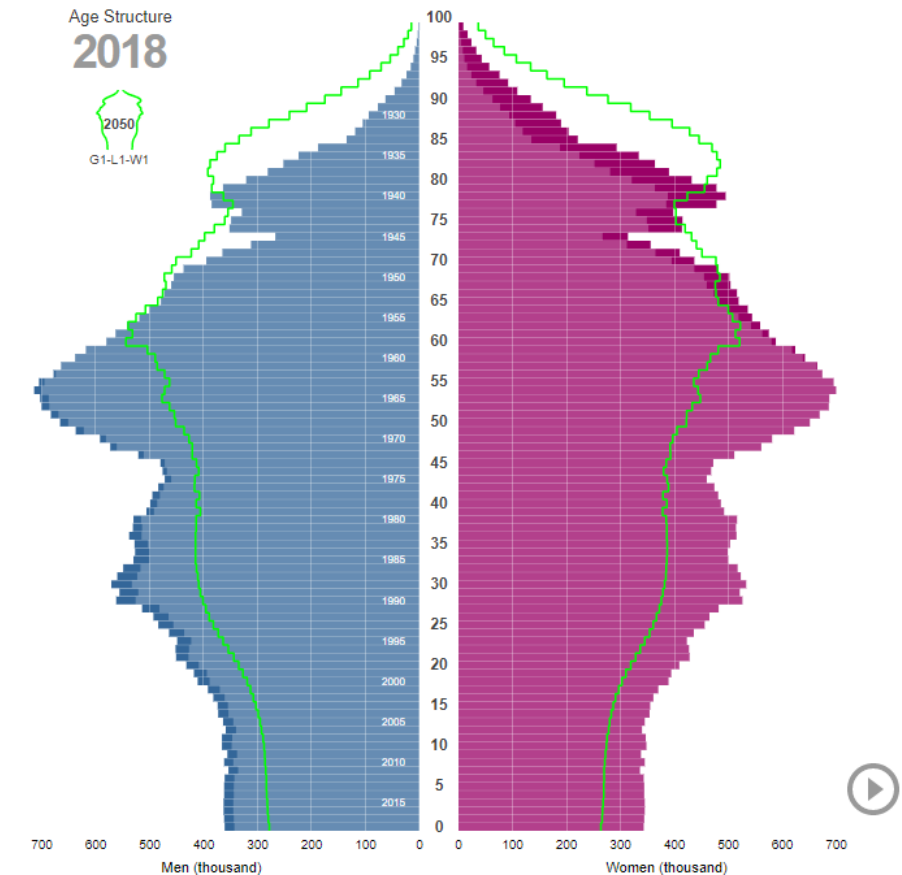
Modular and connected factory for local and profitable production of high-tech components in Bavaria



Geriatrics Project (2019-2027, 8 M., LongLeif Gapa gGmbH): Motivation

- In 2050, the **"65+"** age group will account for more than 32% of the total population (2018: 22%) [1].
- Healthcare staff shortage in the EU28 is anticipated to reach 4.1 million in 2030 (0.6 m. physicians, 2.3 m. nurses and 1.3 m. other care professionals) [2]

How can we use technology to support both elderly and caregivers?



[1] Kalavrezou, N., Pot, M., Kadi, S., Simmons, C., & Leichsenring, K. (2025). *Facts and Figures on Healthy Ageing and Long-Term Care*.

[2] Michel, J. P., & Ecartot, F. (2020). The shortage of skilled workers in Europe: its impact on geriatric medicine. *European geriatric medicine*, 11(3), 345-347.

Geriatrics Project (2019-2027, 8 M., LongLeif Gapa gGmbH)



DAILY LIFE

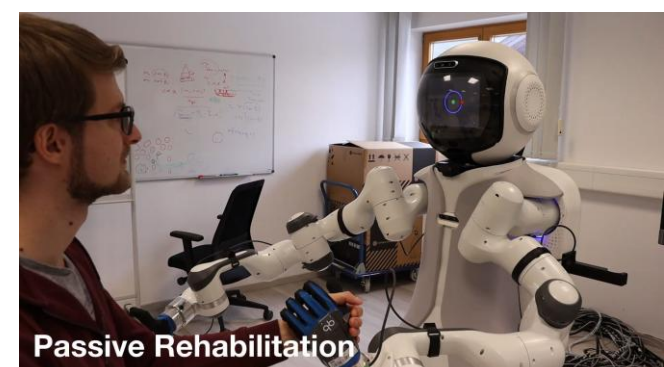
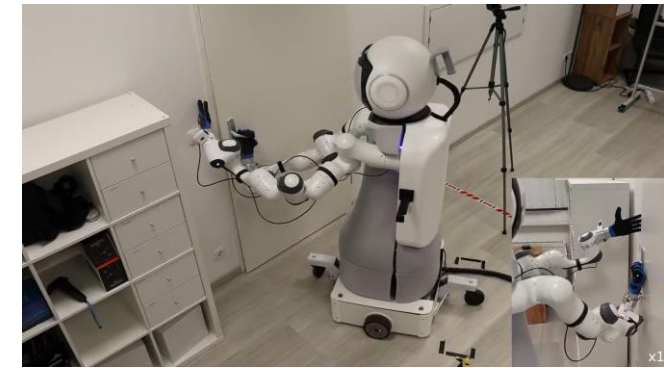
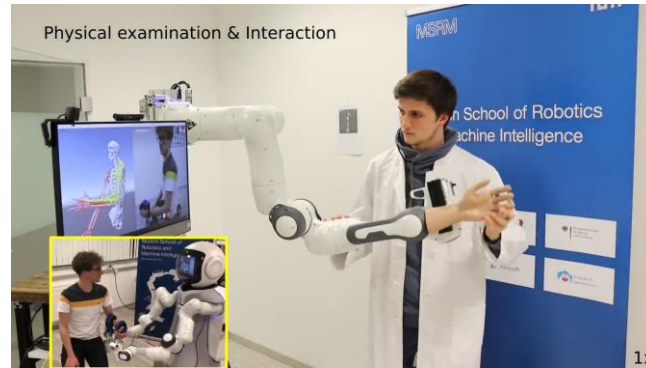
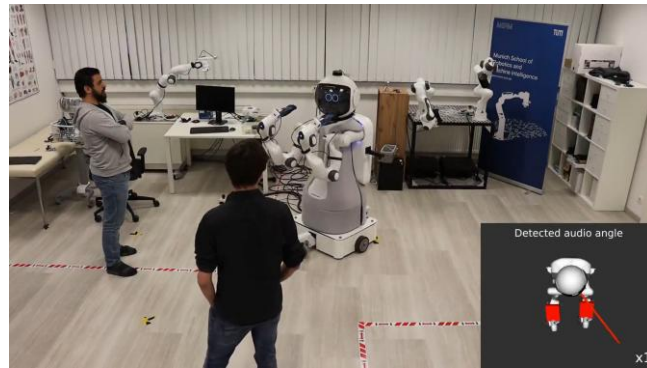
- Fetch objects
- Read out the post
- Reminders
- ...

COMMUNICATION

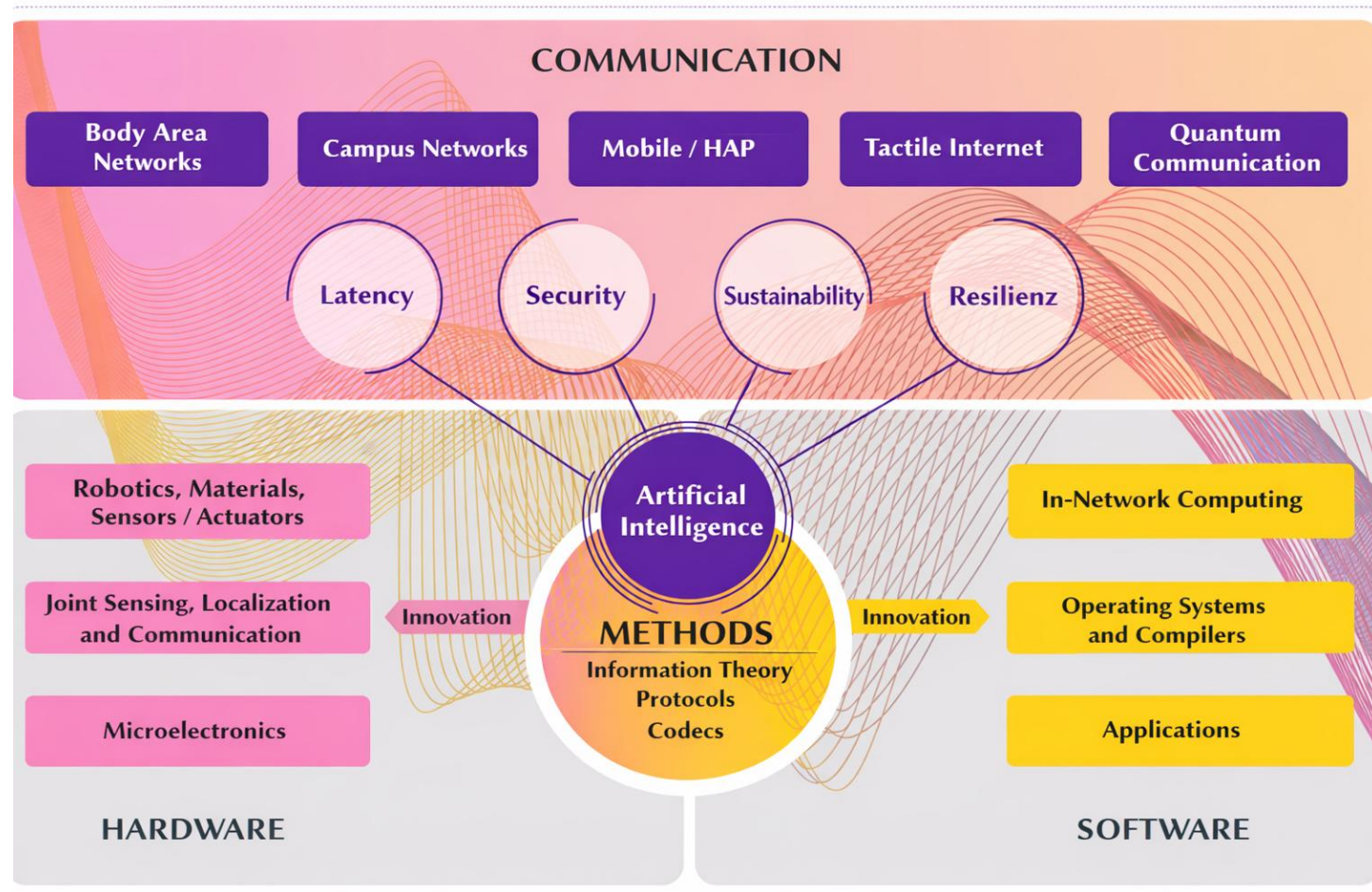
- Multimodal communication with friends & acquaintances
- Teleoperation/Teleteaching
-

HEALTH

- Telemedicine (diagnosis&therapeutic)
- Rehabilitation & fitness
- Assistive and nursing
- ...



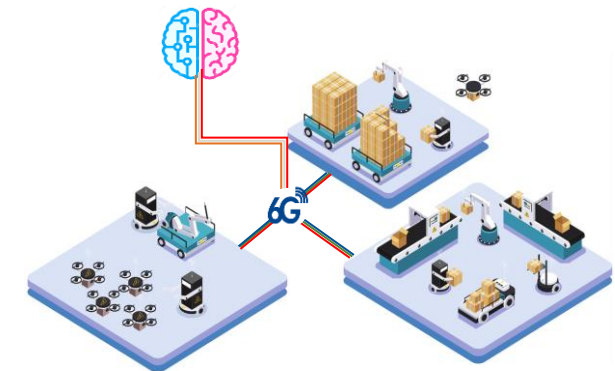
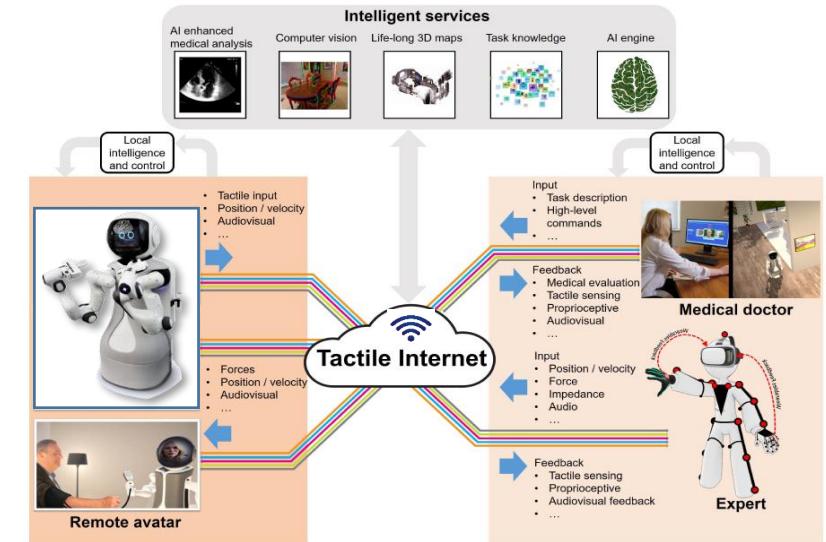
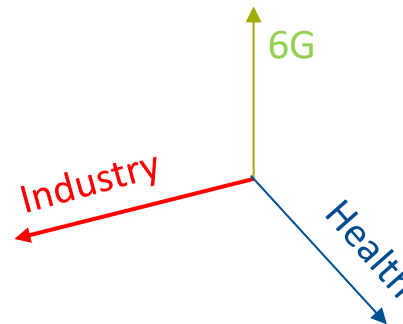
6G-life (2022-2029, 70 M., BMFTR)



Research fields in 6G communication networks with focus on human-machine collaboration

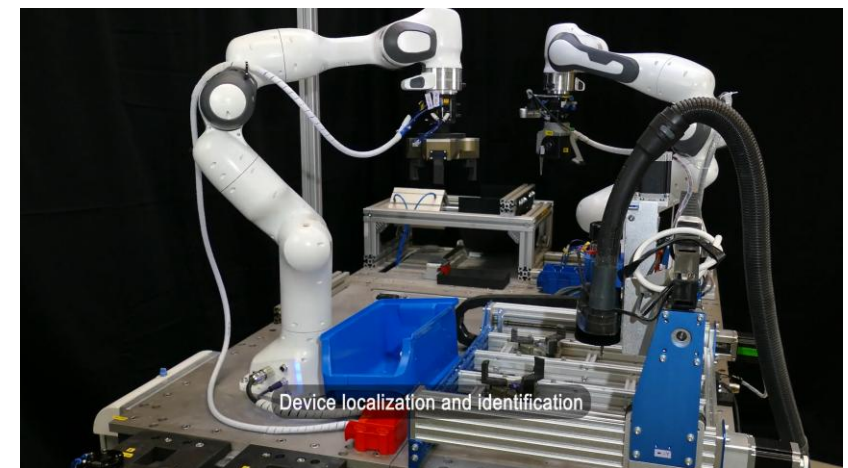
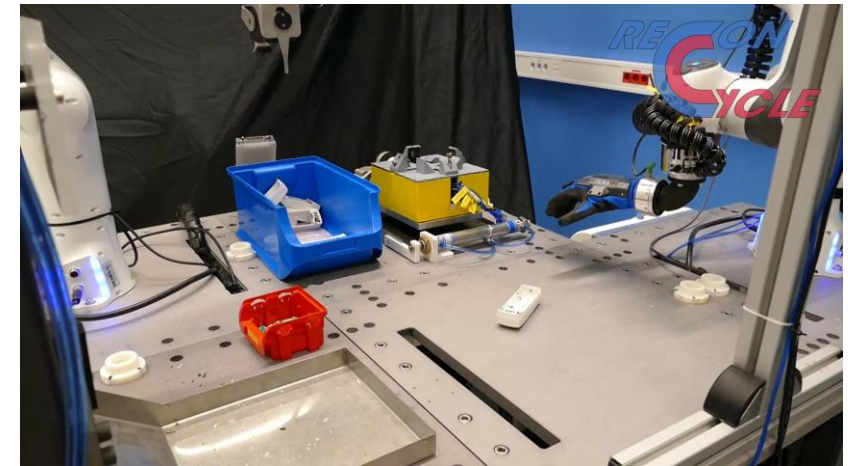
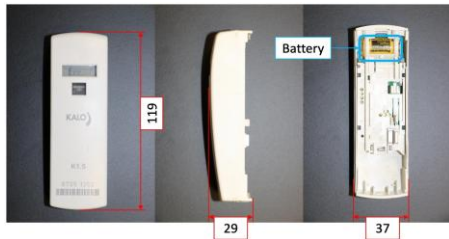
6G-life: 6G in Robotics and Industry

- Development of fault-tolerant and adaptive **remote** control architectures for safety-critical applications
- Lighter, cheaper and more energy efficient physical system by offloading the computations
- Include online information from different sources
- New forms of collaboration within different machine networks of robots
- The 6G-enabled algorithms applied
 - health sector
 - Industry sector



ReconCycle (2021-2025, EU, 7 M.), FlexCycle (2025-2029, EU, 8 M.):

- Reconfigurable robotic work cell for the recycling of electronic waste
- Flexible robotic solutions for the recycling of soft materials such as cables, clothes, membranes,...



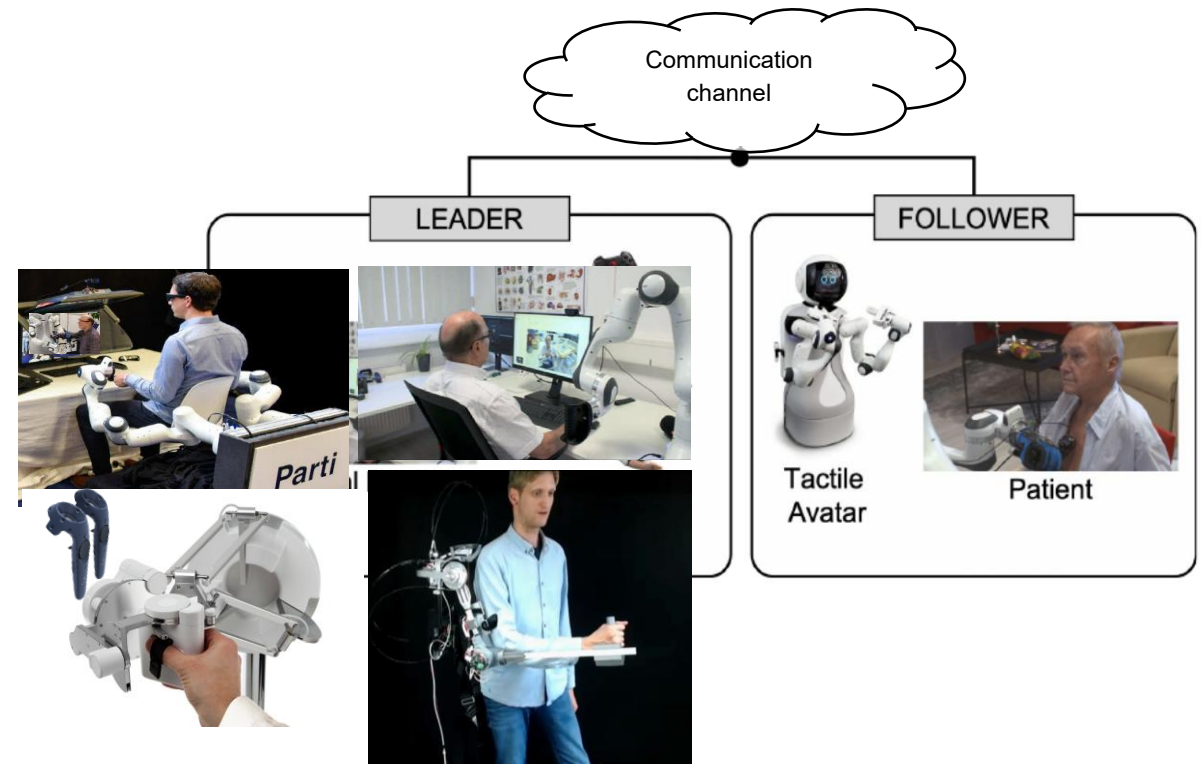
Research Highlights

Research Highlights in Networked and Collaborative Robots

- Tele-examination and tele-diagnosis
- Personalized assistance and tele-rehabilitation
- Exoskeleton
- Tele-surgery over 5G
- Communication challenges
- Control performance and transparency
- Network aware shared autonomy
- Relocation of control in cloud
- Human-Robot collaboration for healthcare and industry
- Force/motion control and tactile skills developments

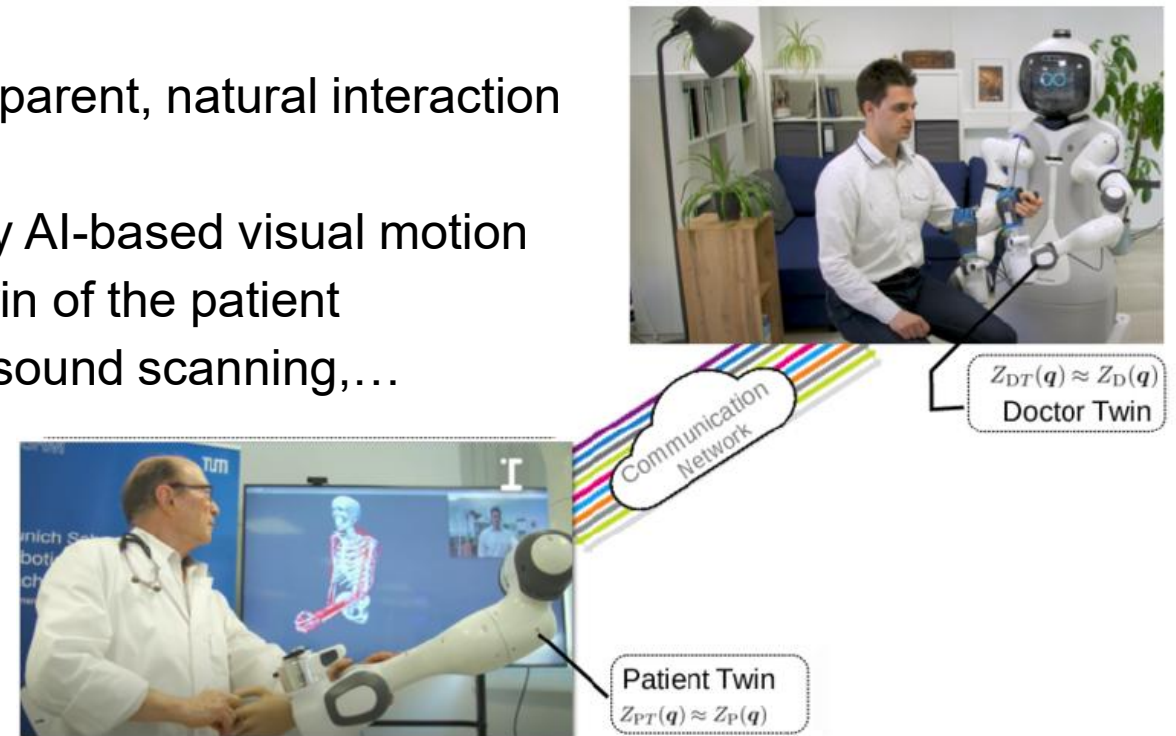
Tactile Teleoperation Station (Avatar)

- Multi-modal interface for remote control of robots
 - Robot arm
 - Bimanual haptic device
 - Joystick, Haptic consol
 - Arm and hand Exoskeleton
 - VR, AR
- Different applications
 - Tele-rehabilitation
 - Tele-examination and Tele-diagnosis
 - Tele-surgery
 - Tele-manipulation (ex. Assembly)
 - Tele-teaching of skills



Tele-examination and Telediagnosis

- Two robots are involved which represent
 - the doctor on the patient side
 - the patient on the doctor side
- A bidirectional telepresence approach enables transparent, natural interaction between doctor and patient
- The knowledge transfer to the doctor is enhanced by AI-based visual motion and facial-expression analysis as well as a digital twin of the patient
- 3D Image transmission, recording parameters, ultrasound scanning,...

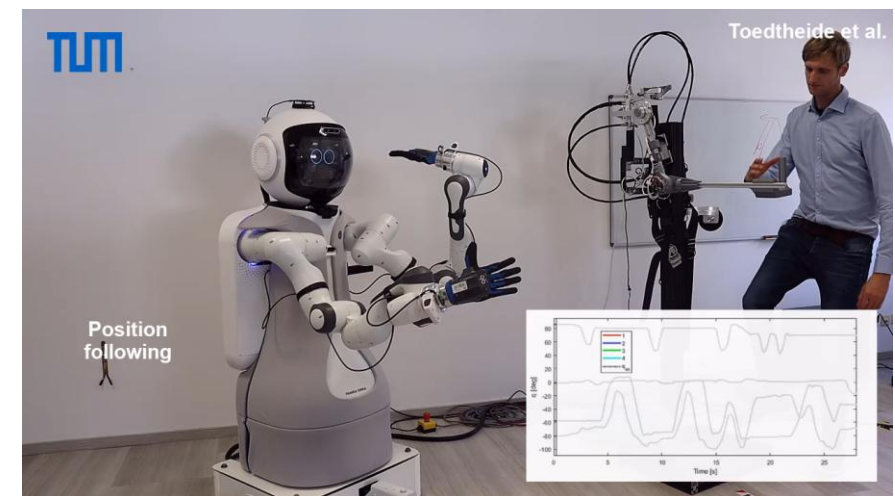
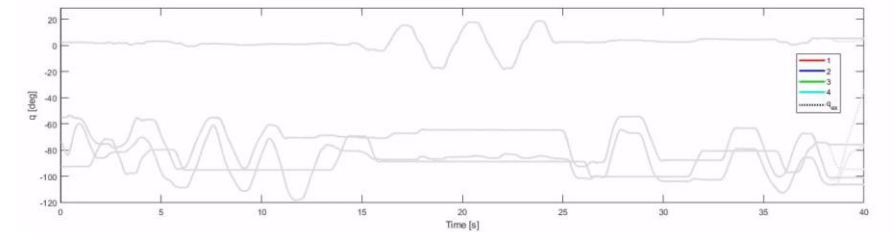
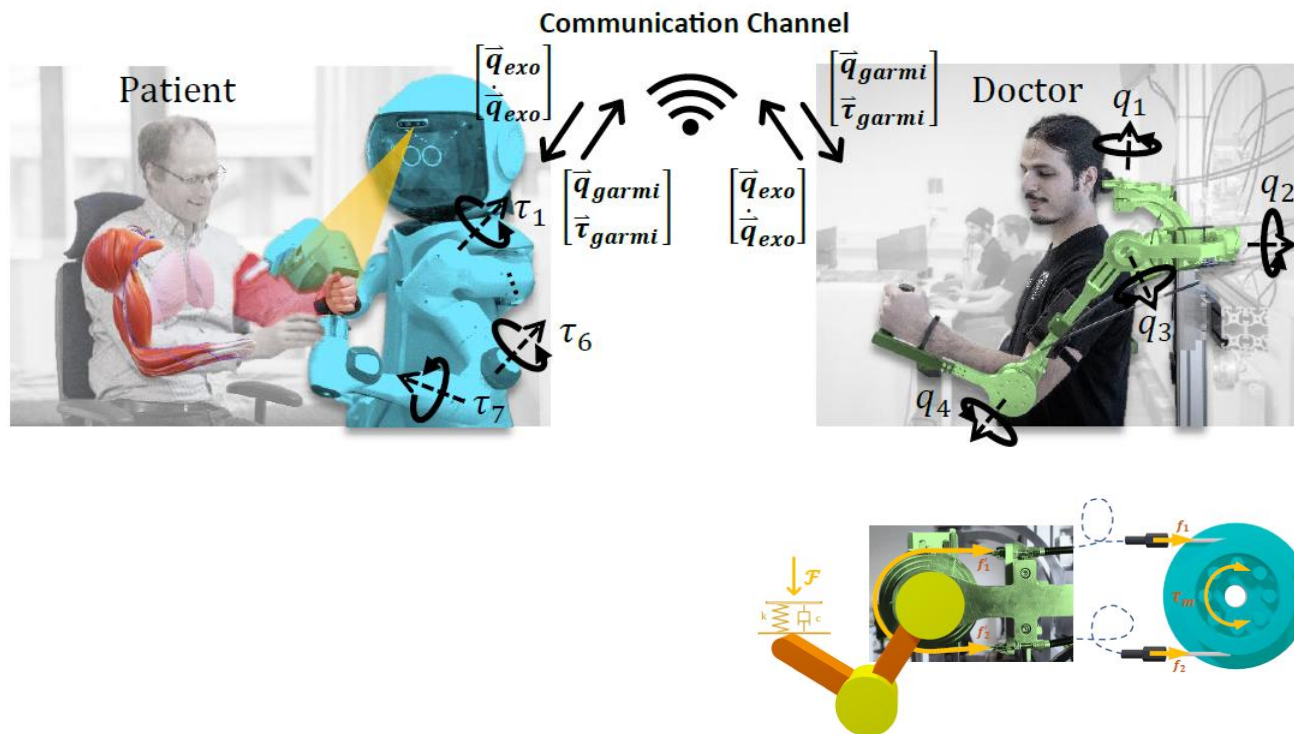


Tele-examination and Telediagnosis



- Naceri, A., Elsner, J., Tröbinger, M., Sadeghian, H., Johannsmeier, L., Voigt, F., ... & Haddadin, S. (2022). Tactile robotic telemedicine for safe remote diagnostics in times of corona: system design, feasibility and usability study. *IEEE Robotics and Automation Letters*, 7(4), 10296-10303.
- Tröbinger, M., Costinescu, A., Xing, H., Elsner, J., Hu, T., Naceri, A., ... & Haddadin, S. (2021, September). A dual doctor-patient twin paradigm for transparent remote examination, diagnosis, and rehabilitation. In *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 2933-2940). IEEE.

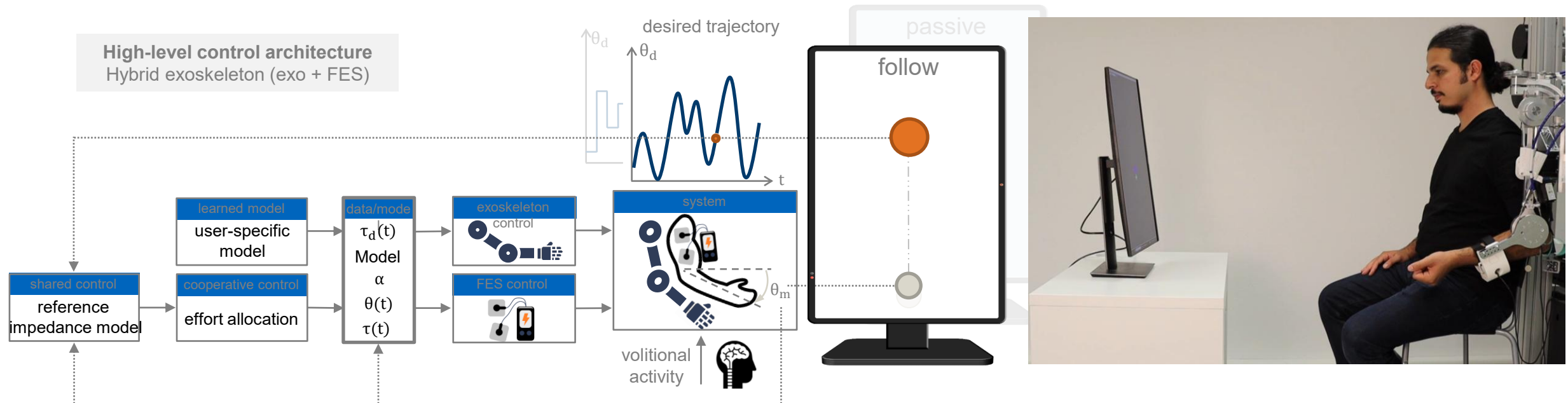
Tele-examination and Telediagnosis - Exoskeleton



Toedtheide, A., Chen, X., Sadeghian, H., Naceri, A., & Haddadin, S. (2023, May). A force-sensitive exoskeleton for teleoperation: An application in elderly care robotics. In *2023 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 12624-12630). IEEE.

Forouhar, M., Sadeghian, H., Suay, D. P., Naceri, A., & Haddadin, S. (2024, October). A Tactile Lightweight Exoskeleton for Teleoperation: Design and Control Performance. In *2024 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 178-183). IEEE.

Tele-rehabilitation: A Hybrid FES-Exoskeleton for active rehabilitation



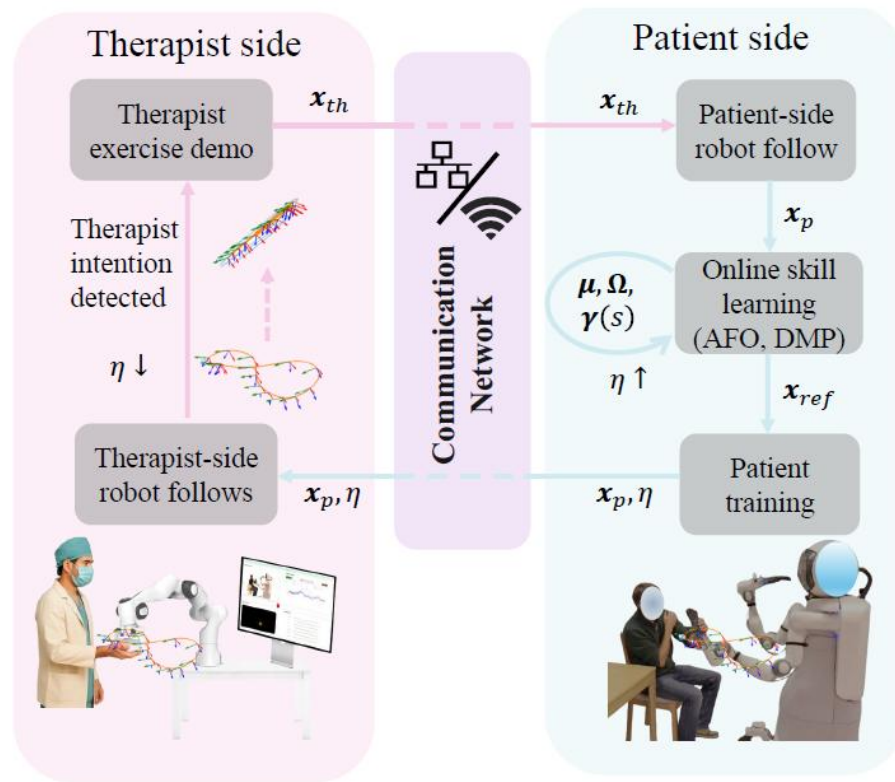
- Kavianirad, H., Forouhar, M., Sadeghian, H., Endo, S., Haddadin, S., & Hirche, S. (2023, September). Model-based shared control of a hybrid FES-exoskeleton: An application in participant-specific robotic rehabilitation. In *2023 International Conference on Rehabilitation Robotics (ICORR)* (pp. 1-6). IEEE.

Tele-rehabilitation: Personalized Assistance and Active rehabilitation



- Chen, X., Sadeghian, H., Li, Y., & Haddadin, S. (2023). Tele-rehabilitation of upper extremity with GARMI robot: concept and preliminary results. *IFAC-PapersOnLine*, 56(2), 3546-3551.
- Pezeshki, L., Sadeghian, H., Keshmiri, M., Chen, X., & Haddadin, S. (2023). Cooperative assist-as-needed control for robotic rehabilitation: A two-player game approach. *IEEE Robotics and Automation Letters*, 8(5), 2852-2859.
- Pezeshki, L., Sadeghian, H., Mohebbi, A., Keshmiri, M., & Haddadin, S. (2025). Personalized Assistance in Robotic Rehabilitation: Real-Time Adaptation via Energy-Based Performance Monitoring. *IEEE Transactions on Automation Science and Engineering*.
- Pezeshki, L., Sadeghian, H., Chen, X., Keshmiri, M., Haddadin, S., & Mohebbi, A. (2025). Assist-as-Needed Framework for Robotic Rehabilitation: Adaptive Admittance Control with Passivity-Based Safety Features. *IEEE Transactions on Medical Robotics and Bionics*.

Tele-rehabilitation: Online Transfer and Adaptation of Skills over Distance

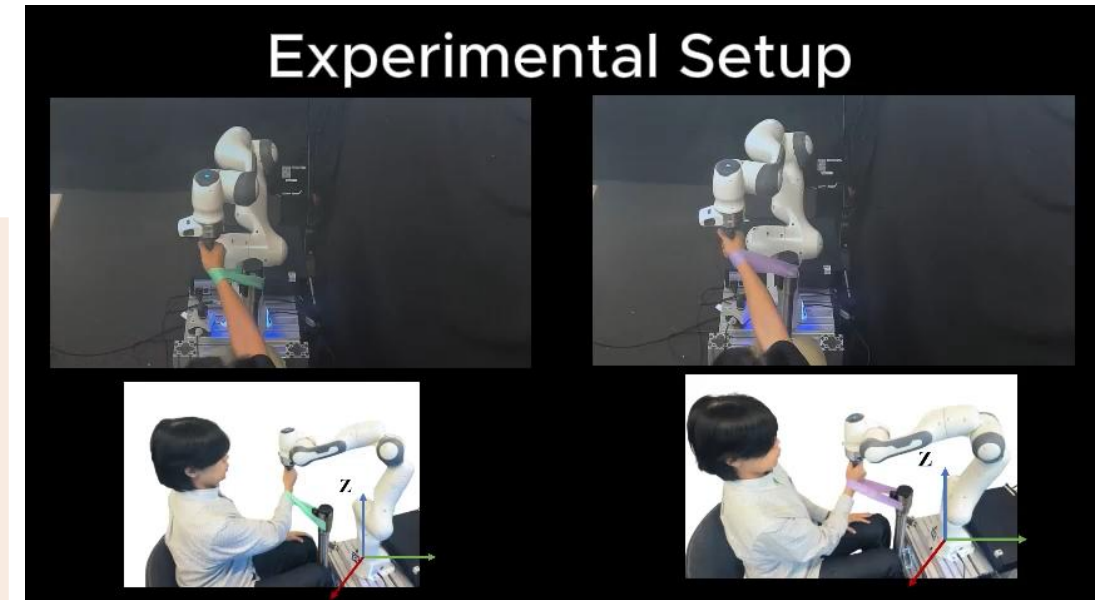
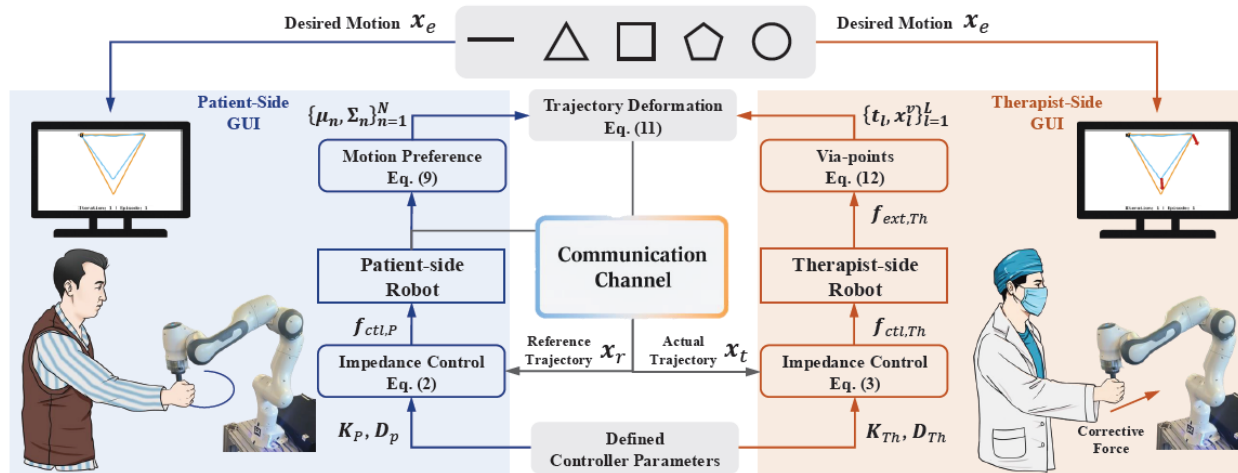


Tele-rehabilitation with online transfer and adaptation of skills in $\mathbb{R}^3 \times S^3$ space

Anonymous Authors

- Chen, X., Ni, T., Karacan, K., Sadeghian, H., & Haddadin, S. (2024). Online Transfer and Adaptation of Tactile Skill: A Teleoperation Framework. In *8th Annual Conference on Robot Learning*.
- Ni, T., Chen, X., Sadeghian, H., & Haddadin, S. (2025). Tele-rehabilitation with online skill transfer and adaptation . *arXiv preprint arXiv:2510.00770*.

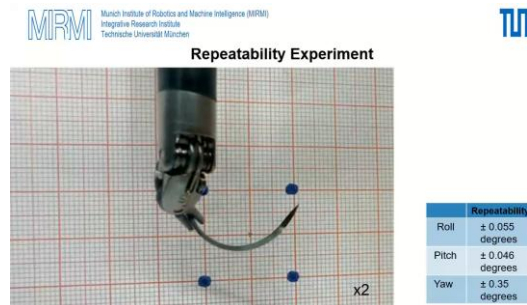
Tele-rehabilitation: Online Transfer and Adaptation of Skills over Distance



- Hou, Z., Hou, J., Chen, X., Sadeghian, H., Ren, T., & Haddadin, S. (2026). Learning a Shape-adaptive Assist-as-needed Rehabilitation Policy from Therapist-informed Input, ICRA 2026

Tele-surgery (safety critical application)

- A base platform with open control structure
- Endow tactile feedback to the hand of surgeon
- Strategies to control the system over distance
- AI-assistants modalities using shared autonomy
- The integration of 5G/6G communication
- Address safety in case of network disturbances



A Modular Research Platform for 5G-enabled Remote Telesurgery

Hamid Sadeghian, Valentin Le Mesle, Fabian Jakob, Celal Umut Kenanoglu, Yu Li, Dirk Wilhelm, Wolfgang Kellerer and Sami Haddadin

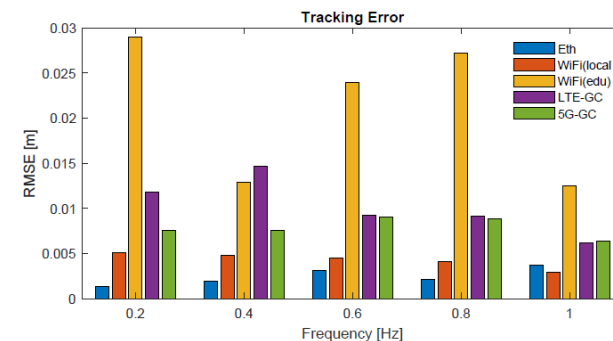
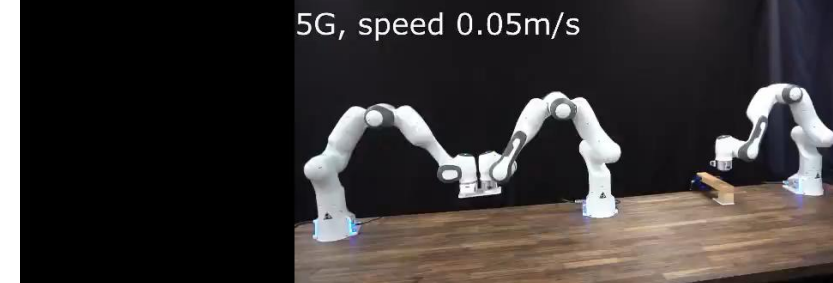
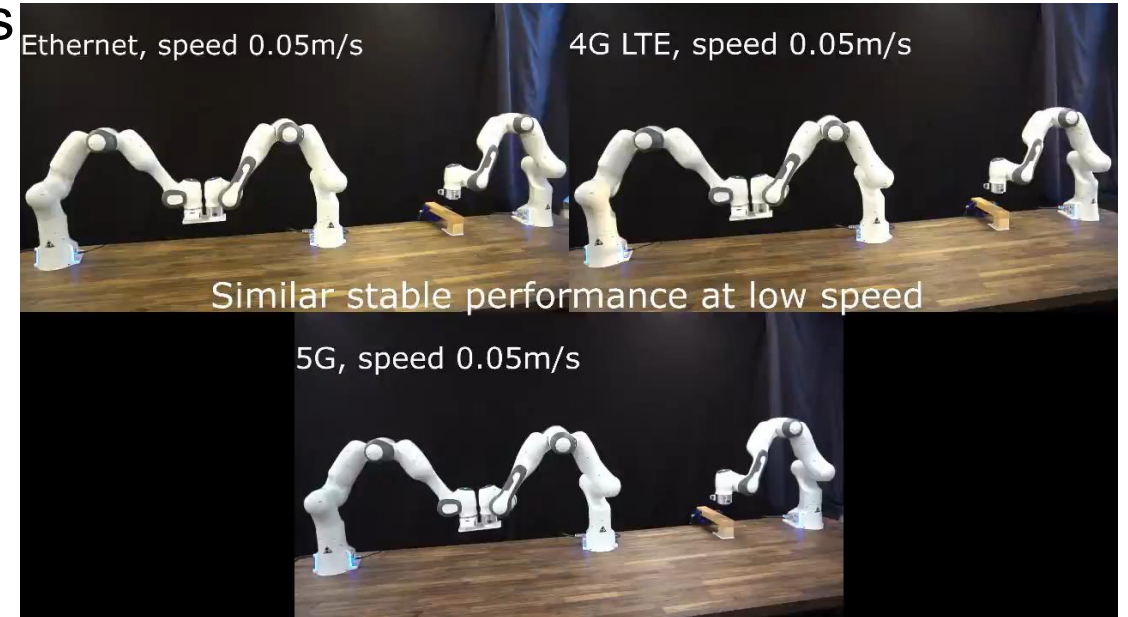
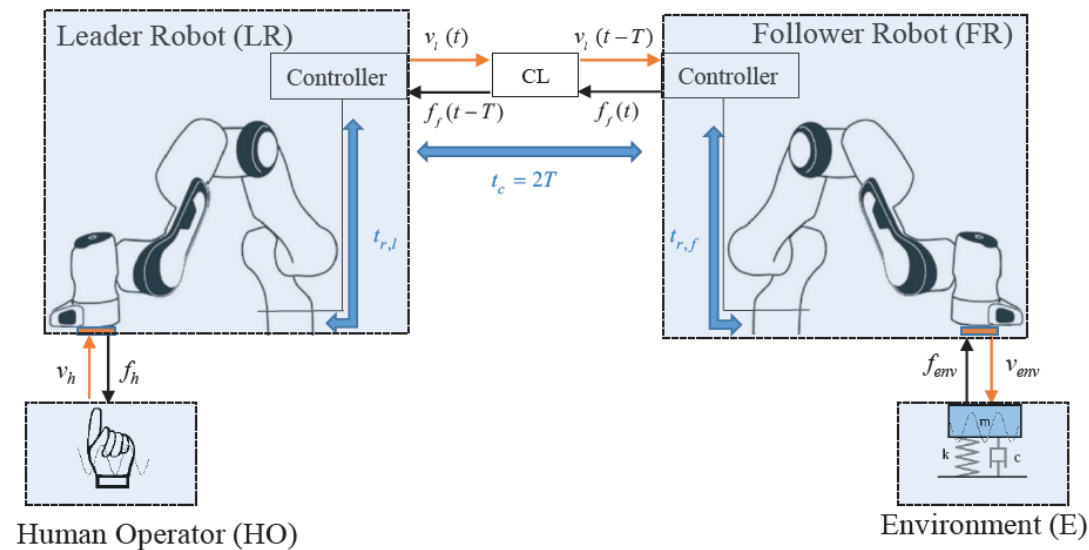
- H. Sadeghian, V. Le Mesle, F. Jakob, C. Kenanoglu, Y. Li, D. Wilhelm, W. Kellerer, and S. Haddadin. A modular research platform for 5g-enabled remote telesurgery. In 1st German Robotic Conference, 2025
- Li, Y., Sadeghian, H., Yang, Z., Mesle, V. L., & Haddadin, S. (2025). Constraint-Consistent Control of Task-Based and Kinematic RCM Constraints for Surgical Robots. *arXiv preprint arXiv:2509.14075*.
- Kenanoglu, C. U., Le Mesle, V., Luarasi, G., Sadeghian, H., & Haddadin, S. (2024, September). Design and Evaluation of a Surgical Tool Drive Unit for Sustainable Training in Robot-Assisted Minimally Invasive Surgery. In *2024 10th IEEE RAS/EMBS International Conference for Biomedical Robotics and Biomechatronics (BioRob)* (pp. 1555-1560). IEEE.

Communication Challenges in Networked Robots

- Communication delay/packet loss:
 - high packet rate (1Khz)
 - Robot stability
 - Transparency (Mechanical, Interface)
 - Synchronization of video and sensory-command data
- Robot stability and physical safety
- Data security

Communication Challenges in Networked Robots

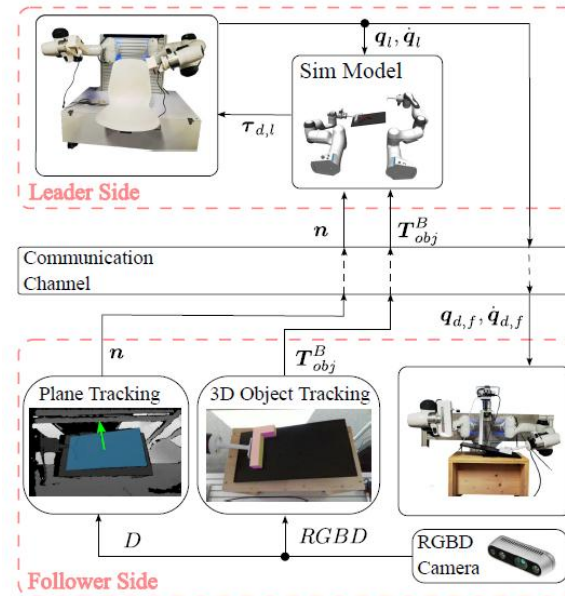
Telepresence reference platform



- Chen, X., Johannsmeier, L., Sadeghian, H., Shahriari, E., Danneberg, M., Nicklas, A., ... & Haddadin, S. (2022, October). On the communication channel in bilateral teleoperation: An experimental study for ethernet, wifi, lte and 5g. In *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 7712-7719). IEEE.

Communication Challenges in Networked Robots: Control Approaches

- Time Domain Passivity Approach (TDPA)
- Model-Mediated-Teleoperation (MMT)
- Network aware shared autonomy





Munich Institute of Robotics and Machine Intelligence (MIRMI)
Integrative Research Institute
Technische Universität München



Model-Mediated Teleoperation with 3D Dynamic Environment Tracking (MMT-DET): A Comparative Study of Task Performance with Time-Domain Passivity Control

Diego Fernandez Prado¹, Xiao Chen¹, Jean Elsner, Hamid Sadeghian, Nader Rajaei, Abdeldjalil Naceri, Sami Haddadin and Eckehard Steinbach

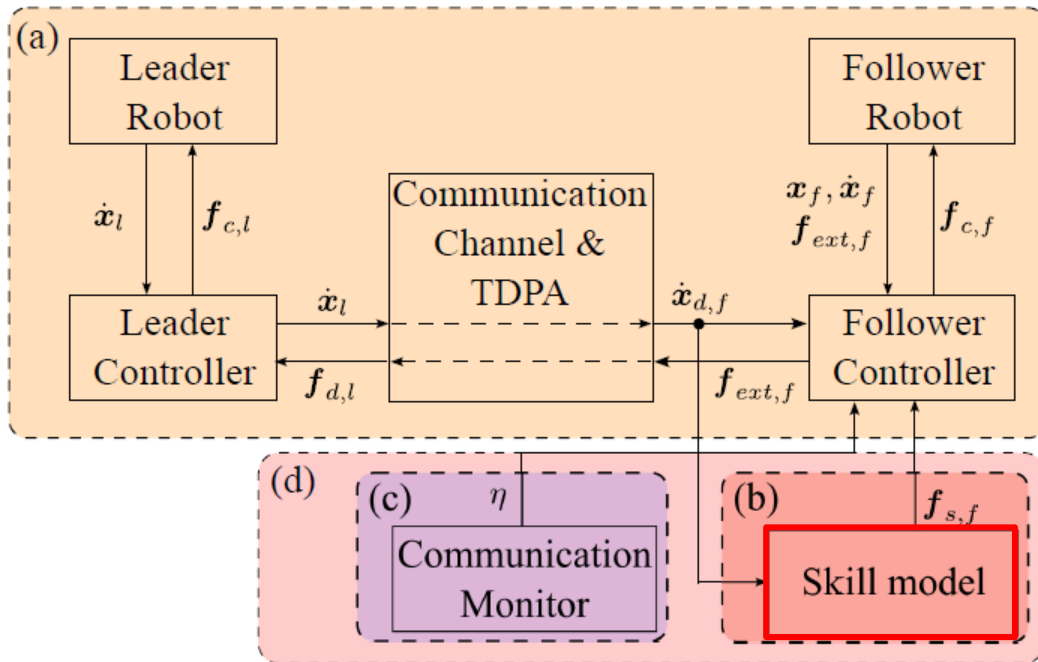
The authors acknowledge the financial support by the Federal Ministry of Education and Research of Germany (BMBF) in the program of "Souverän. Digital. Vernetzt." Joint project 6G-life, project identification number 16KISK002. We gratefully acknowledge the funding of the Lighthouse Initiative Geriatric Robotics by LongLife GaPa gGmbH (Project Y) and the funding of the Lighthouse Initiative KI.FABRIK Bayern by StMWi Bayern, Forschungs- und Entwicklungsprojekt, grant no. DIK0249.

*Authors contributed equally
All authors are with the Munich Institute of Robotics and Machine Intelligence and the Chair of Robotics Science and Systems Intelligence, Technical University of Munich, Munich, Germany



- Fernandez Prado, D., Chen, X., Elsner, J., Sadeghian, H., Rajaei, N., Naceri, A., ... & Steinbach, E. (2025). (MMT-DET): A Comparative Study of Task Performance with Time-Domain Passivity Control. In *2025 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2025)*.

Communication Challenges in Networked Robots: Network aware shared autonomy



MIRMI Munich Institute of Robotics and Machine Intelligence (MIRMI)
Integrative Research Institute
Technische Universität München

TUM

Network-aware Shared Autonomy in Bilateral Teleoperation

Xiao Chen¹, Youssef Michel², Hamid Sadeghian¹, and Sami Haddadin¹

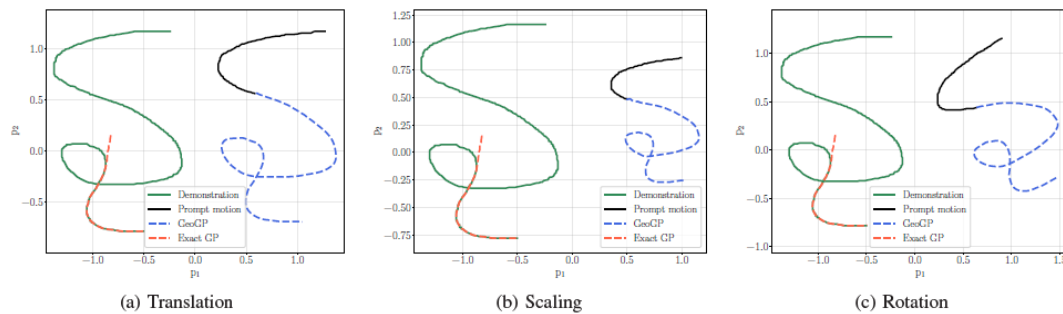
We gratefully acknowledge the funding of the Light-house Initiative Geriatrics by StMWi Bayern (Project X, grant no. IUK-1807-0007// IUK582/001) and LongLeif GaPa gGmbH (Project Y). The authors acknowledge the financial support by the Federal Ministry of Education and Research of Germany (BMBF) in the program of "Souverän. Digital.Vernetzt." Joint project 6G-life, project identification number16KISK002.

¹Authors are with the Munich Institute of Robotics and Machine Intelligence and the Chair of Robotics Science and Systems Intelligence, Technical University of Munich, Munich, Germany

²Authors are with the Human-centered AssistiveRobotics, Technical University of Munich, Munich, Germany.

- Chen, X., Michel, Y., Sadeghian, H., & Haddadin, S. (2024, November). Network-aware shared autonomy in bilateral teleoperation. In *2024 IEEE-RAS 23rd International Conference on Humanoid Robots (Humanoids)* (pp. 888-894). IEEE.
- Wu, Y., Chen, X., Chen, Y., Sadeghian, H., Wu, F., Bing, Z., ... & Knoll, A. (2025). Shared-Assembly: A Data Collection Approach via Shared Tele-Assembly. *arXiv preprint arXiv:2503.12287*.

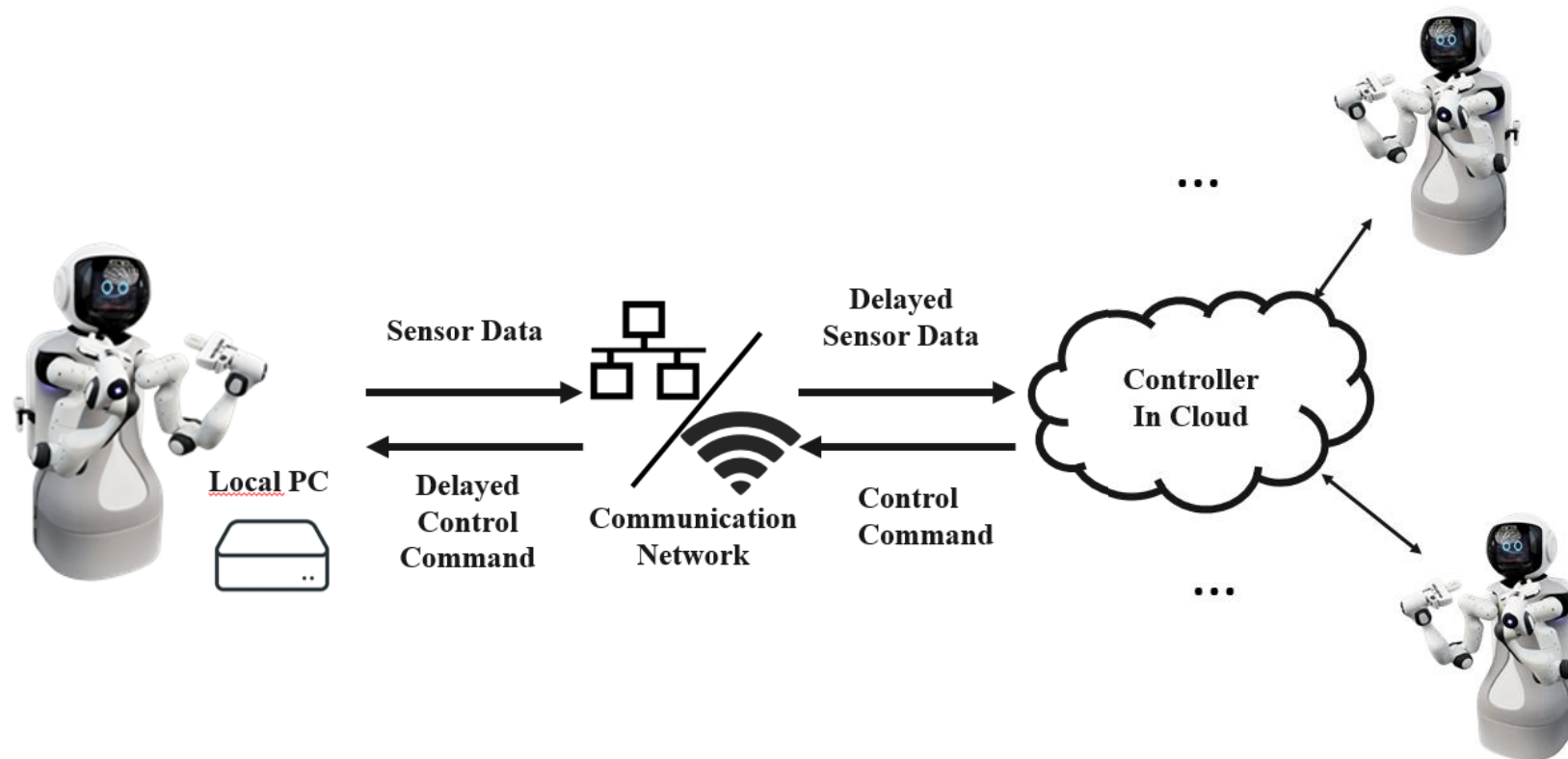
Network aware shared autonomy: Skill Model Development



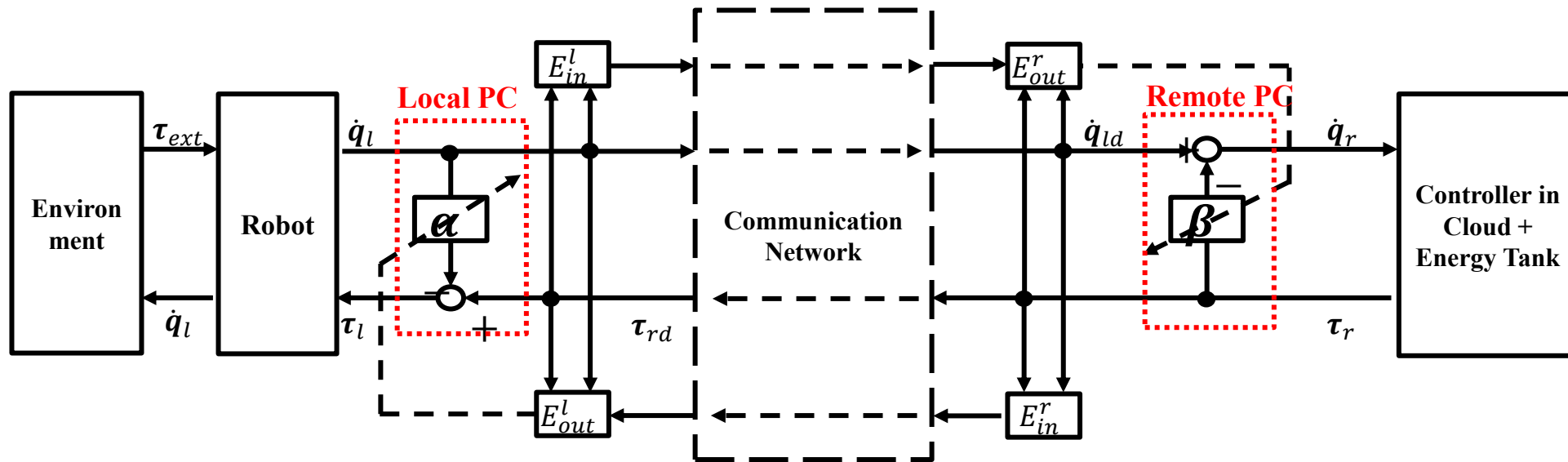
- Yang, Z., Dai, X., Zhang, D., Li, Y., Meng, Z., Huang, B., ... & Haddadin, S. (2025). Prompt2Auto: From Motion Prompt to Automated Control via Geometry-Invariant One-Shot Gaussian Process Learning. *arXiv preprint arXiv:2509.14040*.

Offloading Low Level Controllers to edge-Cloud

Centralize the whole low-level control to the cloud



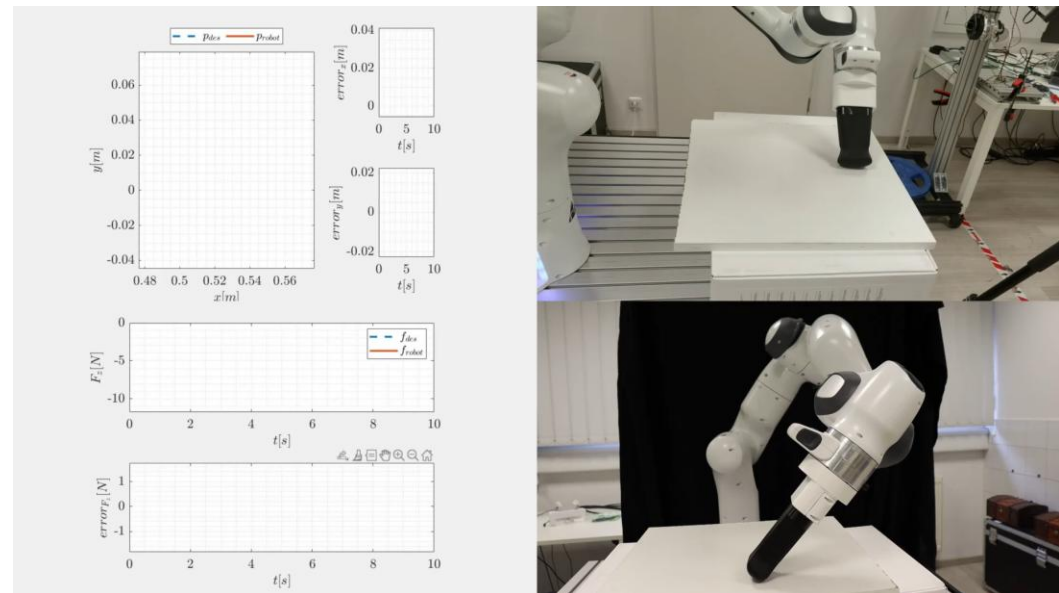
Offloading Low Level Controllers to edge-Cloud: TDPA framework



Offloading Low Level Controllers to edge-Cloud: TDPA framework



$20 \pm 4ms$ delay, without proposed framework, **unstable**



$20 \pm 4ms$ delay, with proposed framework, **stable**

Chen, X., Sadeghian, H., Chen, L., Tröbinger, M., Swirkir, A., Naceri, A., & Haddadin, S. "A Passivity-based Approach on Relocating High-Frequency Robot Controller to the Edge Cloud." *2023 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2023.

Jakob, F., Chen, X., Sadeghian, H., & Haddadin, S. (2024, May). Enhancing the Tracking Performance of Passivity-based High-Frequency Robot Cloud Control. In *2024 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 12097-12103). IEEE.

Thanks for your attention