Research Grants for PhD students from the China Scholarship Council

Joint PhD supervision

DESIGN AND ROBUST CONTROL OF UPPER-LIMB EXOSUITS FOR IMPROVED HUMAN COMFORT AND ASSISTANCE

In the past decade, exoskeleton robots have emerged as a promising solution for assisting individuals with locomotor disabilities and enhancing the physical capabilities of workers in industrial environments. Locomotor disability, the most commonly reported type of disability, refers to a person's inability to perform activities of daily living (ADL) involving movement of the body or objects from one place to another. This limitation typically arises from disorders of the musculoskeletal or nervous systems. Assistive technologies have therefore been widely explored to help individuals with such disabilities engage more effectively in daily activities by augmenting limb strength and improving mobility. In industrial settings, workers are also at risk of developing work-related musculoskeletal disorders (WMSDs). Contributing factors include physical overload, awkward or constrained working postures, and local contact stress. Excessive physical load can lead to muscle fatigue or injury, particularly in muscles such as the biceps, anterior deltoid, and spinal extensors. To mitigate these risks, exoskeleton robots have demonstrated effectiveness in reducing physical strain and improving ergonomic conditions.

Extensive research in wearable assistive robotics has led to the development of rigid-frame exoskeletons for applications ranging from rehabilitation support to strength augmentation. While these systems are capable of delivering substantial forces and torques, they suffer from several inherent limitations. Their relatively large weight and inertia reduce mechanical transparency, often resulting in increased metabolic cost and restricted natural movement due to undesired joint torques. To overcome these limitations, flexible exoskeletons, commonly referred to as exosuits, have attracted growing research interest. Unlike rigid exoskeletons, exosuits are typically constructed from soft materials such as textiles and cables, making them lightweight and more comfortable for users. However, human comfort when using an exosuit remains a challenge. The application of loads to the human body by an upper-limb exosuit may generate excessive contact pressure, potentially compromising both safety and comfort. Both the magnitude and distribution of pressure play critical roles in determining user experience. To ensure safety, the applied pressure should remain below the ischemic threshold (approximately 30 mmHg), beyond which capillary blood flow may be obstructed. It is also important to note that not all regions of the body are suitable for load transmission. Areas around joints should remain unrestricted, and regions with superficial blood vessels or nerves, such as the medial and lateral epicondyles of the upper limb, should be avoided to prevent discomfort or injury. These factors should be considered in the optimization of exosuit design. Besides, the complex and nonlinear friction between the inner cable and the outer sheath degrades control robustness by introducing time delays and inaccuracies in position tracking. Various friction phenomena, including Coulomb friction, viscous friction, stiction, and stick-slip behavior, may arise within the system. Therefore, it is essential to develop a robust control framework for the exosuit.

To enhance system performance during the design phase, additional human comfort criteria will be incorporated into the exosuit design. These criteria will be validated through experimental studies. Subsequently, an optimization framework will be developed to improve overall exosuit performance. Furthermore, to address control inaccuracies, a robust control strategy will be designed for the exosuit control system.

Related recent publications by members of research team:

- Y. Lu *et al.*, "Design and experimental validation of a controller for Bowden-cable actuators subject to friction variation," *IEEE Robotics and Automation Letters*, 2025.
- Y. Lu, Y. Aoustin, and V. Arakelian, "Optimization of design parameters and improvement of human comfort conditions in an upper-limb exosuit for assistance," *Multibody System Dynamics*, vol. 62, no. 4, pp. 433–461, 2024.
- Y. Lu, Y. Aoustin, and V. Arakelian, "Mechatronic design of dynamically decoupled manipulators based on the control performance improvement," *Robotica*, vol. 41, no. 2, pp. 609–631, 2023.
- Y. Lu and V. Arakelian, "A new solution to force analysis including Coulomb friction in mechanism joints," *Mechanism and Machine Theory*, vol. 202, p. 105776, 2024.
- Y. Lu and V. Arakelian, "Torque minimization of dynamically decoupled 3R spatial serial manipulators via optimal motion generation," *WSEAS Transactions on Applied and Theoretical Mechanics*, vol. 18, pp. 161–171, 2023.
- Y. Lu, V. Arakelian, and Y. Aoustin, "Control performance improvement of the decoupled exoskeleton arm," in *Proc. Int. Workshop on Medical and Service Robots*, Cham, Switzerland: Springer, 2025.
- Y. Yang *et al.*, "A novel pneumatic soft exoskeleton rehabilitation glove for extension training to hand rehabilitation," in *Proc. 9th Int. Conf. Automation, Control and Robotics Engineering (CACRE)*, IEEE, 2024.
- Q. Meng, S. Xiang, and H. Yu, "Soft robotic hand exoskeleton systems: Review and challenges surrounding the technology," in *Proc. 2nd Int. Conf. Electrical, Automation and Mechanical Engineering (EAME 2017)*, Atlantis Press, 2017.
- Q. Xie *et al.*, "Design of a soft bionic elbow exoskeleton based on shape memory alloy spring actuators," *Mechanical Sciences*, vol. 14, no. 1, pp. 159–170, 2023.
- Y. Zhang, V. Arakelian. Design, Optimization and control of a cable-driven robotic suit for load carriage. «Gravity compensation in robotics», Springer, pp. 125-146 (2022).
- V. Arakelian, Y. Zhang. An improved design of gravity compensators based on the inverted slider-crank mechanism. ASME Journal of Mechanisms and Robotics, Vol. 11, 034501 (2019).

PHD SUPERVISORS' SKILLS AND COMPETENCIES

PhD Supervisor (University of Shanghai for Science and Technology) : Prof. **Hongliu Yu**

Hongliu Yu, Professor and PhD Supervisor, currently serves as the Director of the Institute of Intelligent Rehabilitation Engineering at the University of Shanghai for Science and Technology and Director of the Shanghai Engineering Research Center of Rehabilitation Devices. He has long been engaged in teaching and research in the field of rehabilitation engineering, with research interests including rehabilitation robotics, intelligent human–machine interaction, and intelligent prosthetics. Professor Yu has published more than 410 academic papers, including over 200 indexed by SCI/EI. He has produced a series of representative works in leading journals such as *IEEE Transactions on Neural Networks and Learning Systems*, IEEE Journal of Biomedical and Health Informatics, IEEE/ASME Transactions on Mechatronics, Applied Soft Computing, and the Journal of NeuroEngineering and Rehabilitation. His research spans multiple areas, including rehabilitation robot control, electromyography (EMG) pattern recognition and human–machine cooperative control, demonstrating strong and sustained innovation capability and international academic competitiveness. He holds several academic positions, including Chair of the Asian Alliance of Rehabilitation Engineering and Assistive Technology, Chair of the IEEE International Conference on Rehabilitation Robotics, Editor-in-Chief of Intelligent Rehabilitation and Engineering, and Chair of the 12th and 17th International Convention on Rehabilitation Engineering and Assistive Technology (i-CREATe).

PhD Supervisor (INSA Rennes) : Prof. **Vigen ARAKELYAN**

Since joining the National Institute of Applied Sciences (INSA), Rennes, in 2002, Professor **Vigen Arakelian** has been teaching kinematics and dynamics of mechanisms, mechanical systems design and robotics. In addition to his academic work, he provides expert consultation on complex mechanical systems, delivering high-quality innovative design and engineering solutions based on his extensive research and decades of industrial experience in senior positions.

Development of a methodological framework and technical solutions for wearable walking-assistance devices. The approach studied proposes a solution for the design of portable assistive systems. It can be highlighted for its strong potential to address a real need for conceptual innovation and for the use of exoskeleton technologies.

Author of 3 books and editor of 4 books, with more than 250 papers in international peer-reviewed journals, conferences and book chapters Holder of 23 patents. Extensive experience in research supervision, including 20 completed PhD theses and 14 Master's theses.

Co-supervisor of the PhD thesis (University of Shanghai for Science and Technology): Dr. **Yaogong Lu**

Yaodong Lu is an Associate Professor at the University of Shanghai for Science and Technology. He completed his PhD in 2024 at INSA Rennes under the supervision of Vigen Arakelian. He subsequently carried out postdoctoral research in 2026 at Sorbonne University with Nathanaël Jarrassé, a leading expert in exoskeleton robotics. His research focuses on exoskeleton dynamics modeling, physical human–robot interaction, and control systems. He has published in several leading international robotics journals, including IEEE Robotics and Automation Letters, Mechanism and Machine Theory, Multibody System Dynamics, and Robotica.

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