





Human-Robot Teaming (HRT), a forward leap into real life applications

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Summary



1 Introduction

2 Applications of Industry 5.0 and HRT

Artificial Intelligence, Biomechatronics, and Collaborative Robotics



Podcast: Among Us: Human-Robot Teaming



Rise of Human-Robot Teaming (HRT)

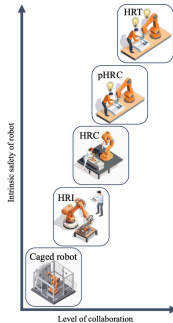


Figure: Transition to Human-Robot Teaming (HRT).

Rise of Human-Robot Teaming (HRT):

- robotics has evolved rapidly with applications across various sectors;
- rise of collaborative robots (cobots) operating safely alongside humans or in shared environments;
- compliant actuators crucial for safe collaboration of cobots and humans;
- elastic joints preferred in dynamic settings for energy absorption during collisions.

Explainable, Reliable and Trustworthy:

- explainable algorithms;
- reliable control;
- trustworthy behaviour.

[1]

[1] Minh Tuan Hua et al. "From rigid to hybrid/soft robots: Exploration of ethical and philosophical aspects in shifting from caged robots to human-robot teaming". In: *Proc. of the IEEE Symposium Series on Computational Intelligence (SSCI)*. 2023, pp. 1794–1799.



Applications of Industry 5.0 and HRT



Smart Healthcare

- ✓ Remote Patient Monitoring.
- ✓ Robot Assisted Surgeries.
- ✓ Electronic Health Records.



Smart Education

- ✓ Enhanced Teaching and Learning Experience.
- ✓ Increased Learning Outcomes and fewer Inequalities.
- ✓ High-Quality Education and Training.



Cloud Manufacturing

- ✓ Enhanced Collaboration.
- ✓ Diverse Information Sharing.
- ✓ Data Analysis and Cloud Computing.



Supply Chain Management

- ✓ Real-time Tracking of Goods.
- ✓ Blockchain Technology for Secure Records.
- ✓ Collaborative Supply Chain.



Sustainable Manufacturing

- ✓ Reduced Waste, Energy Consumption, and Greenhouse Gas Emissions.
- ✓ Improved Resource Efficiency and Low Cost.
- ✓ Adaption to Changing Market.



Disaster Management

- ✓ Early Warnings System.
- ✓ Remote Sensing Technologies.
- ✓ Social Media Analysis.



[2]

[2] Muhammad Hamza Zafar, Even Falkenberg Langås, and Filippo Sanfilippo. "Exploring the synergies between collaborative robotics, digital twins, augmentation, and industry 5.0 for smart manufacturing: A state-of-the-art review". In: *Robotics and Computer-Integrated Manufacturing* 89 (2024), p. 102769.



Challenges in Compliant Cobots for Prosthetics and Orthotics



Figure: A woman wearing a prosthetic leg.

Challenges in Compliant Cobots for Prosthetics and Orthotics:

- despite advantages, compliant cobots are often prohibitively expensive or difficult to build.
- particularly challenging in prosthetics and orthotics where compliance is critical for safety and natural movement.



Open-source Low-cost Elastic Actuators for Prosthetics and Orthotics

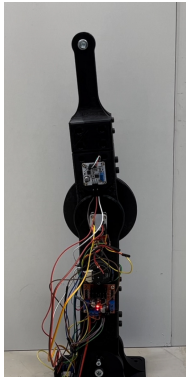


Figure: The proposed elastic actuator.

[3]

Affordable Customisable Open-Source Elastic Actuators:

- an innovative low-cost sensorised elastic joint design for prostheses and orthotics.
- modular design for easy customisation using 3D printing technology.
- implementation of impedance and admittance control techniques for greater versatility.

Open-Source Hardware and Software:

- fully accessible to researchers and practitioners.
- <https://github.com/Microttus/HapticSommerSchool>



[3] Filippo Sanfilippo et al. "Open-source design of low-cost sensorised elastic actuators for collaborative prosthetics and orthotics". In: *HardwareX* 19 (2024), e00564.



Series Elastic Actuator (SEA)

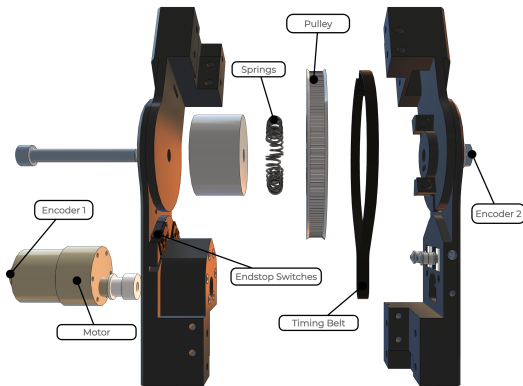


Figure: Exploded view of drive system.

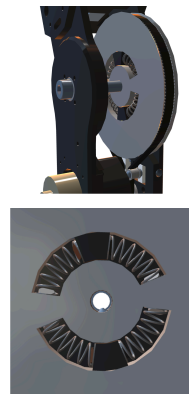


Figure: Series elastic actuator (SEA).



Experimental Results



[3]

Current Robot Control Interfaces



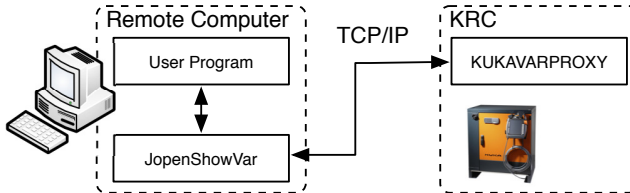
- Over the IoT, cyber-physical systems communicate and cooperate with each other and with humans.
- Value chain.
- Need for standards, sustainability, scalability.

Open vs. Closed Robot Systems:

- the disclosure of the internal control architecture is very hard to come by;
- many manufacturers are unwilling to publish internal details regarding system architecture due to the high levels of competition in the robot market.



JOpenShowVar



A Java open-source cross-platform communication interface that makes it possible to read and write all of the controlled manipulator variables:

- different input devices;
- sensors;
- alternative control methods.

JOpenShowVar works as a *middleware* between the user program and the KRL. Available at <https://github.com/aauc-mechlab/jopenshowvar>^[4,5].

[4] Filippo Sanfilippo et al. "Controlling Kuka industrial robots: Flexible communication interface JOpenShowVar". In: *IEEE Robotics & Automation Magazine* 22.4 (2015), pp. 96–109.

[5] Filippo Sanfilippo et al. "JOpenShowVar: an open-source cross-platform communication interface to kuka robots". In: *Proc. of the IEEE International Conference on Information and Automation (ICIA), Hailar, China. 2014*, pp. 1154–1159.

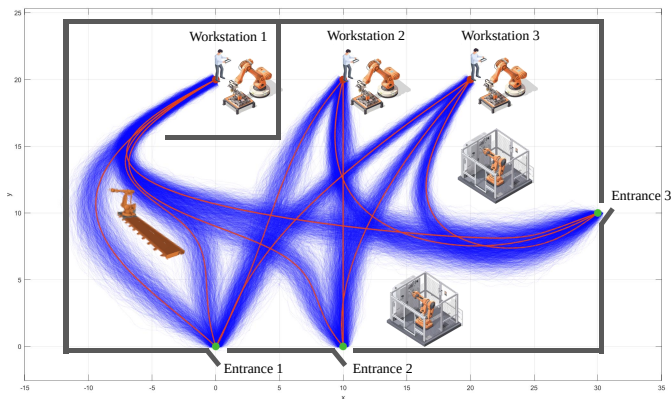
Experimental Results



[4,5]



Human Trajectories Using the Ornstein-Uhlenbeck Process and Deep Learning Based Classification

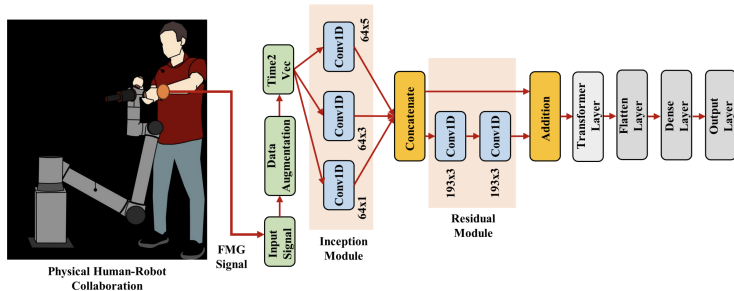


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Hierarchical Recurrent-Inception Residual Transformer (HRIRT) for Multi-Dimensional Hand Force Estimation using Force Myography Sensor



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[7] Muhammad Hamza Zafar, Syed Kumayl Raza Moosavi, and Filippo Sanfilippo. "Hierarchical Recurrent-Inception Residual Transformer (HRIRT) for Multi-Dimensional Hand Force Estimation using Force Myography Sensor". In: *IEEE Sensors Letters* (2024).



EMPERA: Event-Based Multitask Learning Model with Motion Dynamics and Event Density Analysis for Joint Person-Action Recognition



- Number of Parameters: 1.45M
- Up to 15 Action Classes and 15 Subjects
- With >98%

[8,9]

[8] Muhammad Hamza Zafar, Syed Kumayl Raza Moosavi, and Filippo Sanfilippo. "Neuromorphic Event Camera-based Object Recognition and Grasping Position Detection Using a Transfer Learning-Enhanced Multi-Task Model". In: *IEEE Transactions on Automation Science and Engineering* (2025).

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Neuromorphic Vision Human Focus Estimation for Safe Physical Human-Robot Collaboration



- **Real-Time Safety Enhancement:** Event cameras provide microsecond response times to detect attention loss, enabling immediate robot safety interventions to prevent collisions during close collaboration.
- **Adaptive Robot Behavior:** Robots dynamically adjust speed, trajectory, and interaction patterns based on human attention states to optimize collaboration efficiency.
- **Proactive Task Management:** System predicts distraction or fatigue and automatically pauses operations, provides cues, or redistributes tasks to maintain workflow continuity.
- **Enhanced Ergonomics and Comfort:** Focus estimation recognizes cognitive overload, enabling intelligent task scheduling and workload balancing to reduce mental fatigue.
- **Superior Performance in Dynamic Environments:** Event cameras excel in challenging lighting and motion conditions common in industrial settings, providing robust detection regardless of environment.
- **Intelligent Human-Robot Interface:** Enables seamless transitions between autonomous operation and collaborative assistance based on detected human engagement levels.



Neuromorphic Vision Human Focus Estimation for Safe Physical Human Robot Collaboration



[10]

[10] Muhammad Hamza Zafar, Syed Kumayl Raza Moosavi, and Filippo Sanfilippo. *Applications of Neuromorphic/Event Camera in Robotics with Human in Loop: A Systematic Review, Datasets, and Challenges*. Submitted to IEEE Transactions on Human Machine Systems. 2025.



Human-Robot Teaming (HRT): Challenges



[11,12]

Challenges:

- robots for pHRI are advancing to becoming **autonomous co-workers**;
- it is challenging to **sense human motions and behaviour**;
- there is a gap between the desire for humans and robots to work closely together and share control of operations, and **how robustly we can measure and predict human motions and intentions**.

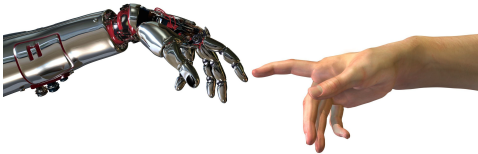
⇒ trade-off between control and mechanical/software design

[11] Filippo Sanfilippo, Houxiang Zhang, and Kristin Ytterstad Pettersen. "The New Architecture of ModGrasp for Mind-Controlled Low-Cost Sensorised Modular Hands". In: *Proc. of the IEEE International Conference on Industrial Technology (ICIT2015), Seville, Spain. 2015*, pp. 524–529.

[12] Filippo Sanfilippo. "Combining grasping with adaptive path following and locomotion for modular snake robots". In: *International Journal of Mechanical Engineering and Robotics Research* 11.2 (2022), pp. 59–65.



Bio-inspired Robotic Hands and Modular Grasping



Mimicking the human hand's ability, one of the most challenging problem in bio-inspired robotics:

- large gap in terms of performances.

Classical approach, analysis of the kinematic behavior of the human hand:

- simplified human hand models with minimum and optimal degrees of freedom^[13].

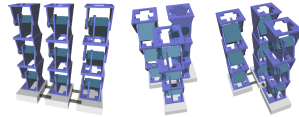
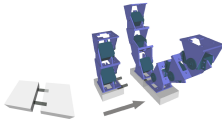
Modular grasping, a promising solution:

- minimum number of degrees of freedom necessary to accomplish the desired task.

[13] S. Cobos, M. Ferre, and R. Aracil. "Simplified human hand models based on grasping analysis". In: *Proc. of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 2010, pp. 610–615.



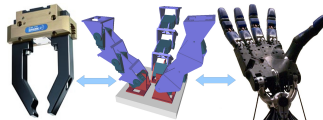
Modular Grasping



- A trade off between a simple gripper and more complex human like manipulators.
- *Principle of minimalism*: choose the simplest mechanical structure, the minimum number of actuators, the simplest set of sensors, etc.

Modular grasping:

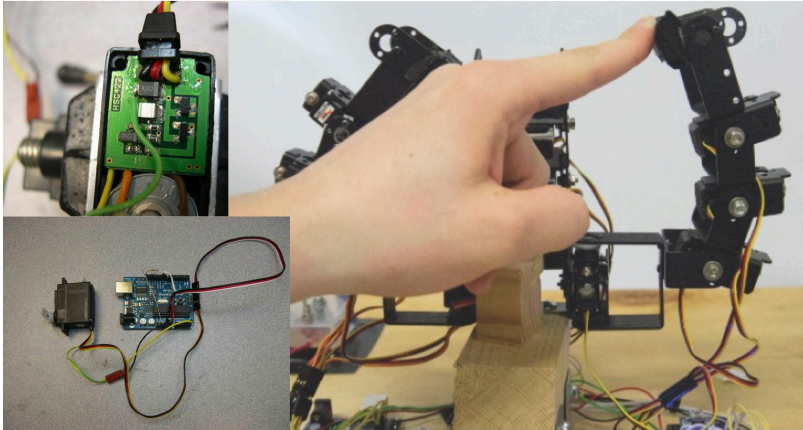
- identical modules are used to build linkages to realise the grasping functions. The modular grasping meets the requirements of standardisation, modularisation, extendibility and low cost^[14].



[14] Filippo Sanfilippo et al. "Efficient modular grasping: an iterative approach". In: *Proc. of the 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob)*, Rome, Italy. 2012, pp. 1281–1286.



Low-cost Torque Sensing and Joint Compliance



Human-Inspired Control



[15]



[15] M. Santello, M. Flanders, and J. F. Soechting. "Postural hand synergies for tool use". In: *The Journal of Neuroscience* 18.23 (1998), pp. 10105–10115.



Experimental Results



Closing the Loop with Haptics



[11]



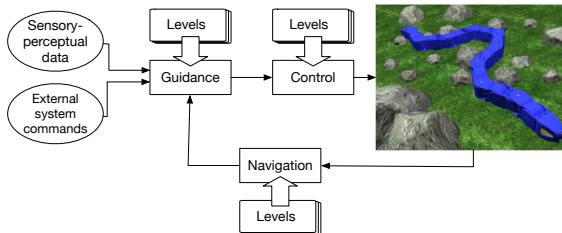
Biological Snakes Capabilities



[16]

[16] Shigeo Hirose and Hiroya Yamada. "Snake-like robots [tutorial]". In: *IEEE Robotics & Automation Magazine* 16.1 (2009), pp. 88–98.

Perception-driven Obstacle-aided Locomotion (POAL)



Perception-driven obstacle-aided locomotion (POAL):

- locomotion where the snake robot utilises a sensory-perceptual system to perceive the surrounding operational environment, for means of propulsion.

[17–19]

[17] Filippo Sanfilippo et al. "A review on perception-driven obstacle-aided locomotion for snake robots". In: *Proc. of the 14th International Conference on Control, Automation, Robotics and Vision (ICARCV)*, Phuket, Thailand. 2016, pp. 1–7.

[18] Filippo Sanfilippo et al. "Virtual functional segmentation of snake robots for perception-driven obstacle-aided locomotion". In: *Proc. of the IEEE Conference on Robotics and Biomimetics (ROBIO)*, Qingdao, China. 2016, pp. 1845–1851.

[19] Filippo Sanfilippo et al. "Perception-driven obstacle-aided locomotion for snake robots: the state of the art, challenges and possibilities". In: *Applied Sciences* 7.4 (2017), p. 336.



Soft Robotics and Compliant Elastic Actuators



[20–22]

-
- [20] **Filippo Sanfilippo et al.** "Serpens: A Highly Compliant Low-Cost ROS-Based Snake Robot with Series Elastic Actuators, Stereoscopic Vision and a Screw-Less Assembly Mechanism". In: *Applied Sciences* 9.3 (2019), p. 396.
- [21] **Hareesh Chitikena et al.** "Adaptive manoeuvring control for planar snake robots in uncertain friction environments". In: *Proc. of the IEEE American Control Conference (ACC)*. 2024, pp. 2844–2850.
- [22] **Hareesh Chitikena et al.** "Anisotropic Friction Skin for Holonomic Snake Robot Mobility". In: *Proc. of the IEEE International Conference on Advanced Robotics and Its Social Impacts (ARSO)*. 2024, pp. 222–227.



Soft robotics and compliant elastic actuators



[20,23]

[23] Minh Tuan Hua et al. "Robust-Adaptive Two-Loop Control for Robots with Mixed Rigid-Elastic Joints". In: *Proc. of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2024)*, Abu Dhabi, United Arab Emirates. 2024.

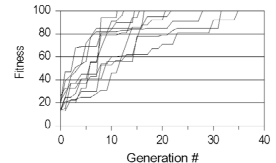
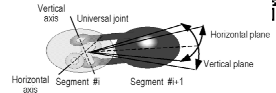


Evolutionary design of snake robot sidewinding locomotion

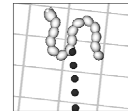


Only a few works can be found in the literature:

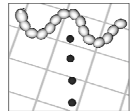
- An automatic design approach was presented by Tanev et al. through genetic programming (GP) to achieve the fastest possible (side-winding) locomotion of simulated limbless, wheel-less snake-like robots.
- Reduction of the search space of the GP is achieved by representing the snake robot as a system comprising identical segments and by automatic definition of code fragments, shared among (and expressing the correlation between) the evolved dynamics of the joint angles.



a)



b)



c)

[24]

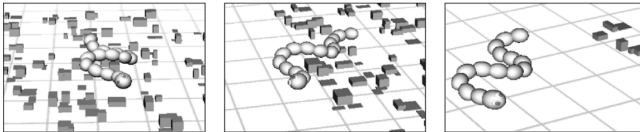
[24] Ivan Tanev, Thomas Ray, and Andrzej Buller. "Automated evolutionary design, robustness, and adaptation of sidewinding locomotion of a simulated snake-like robot". In: *IEEE Transactions on Robotics* 21.4 (2005), pp. 632–645.



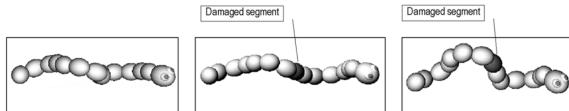
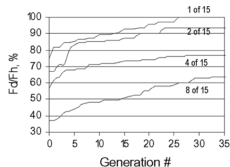
Evolutionary design of sidewinding locomotion of snake-like robots



Locomotion in cluttered environments.



Robustness to failures^[24].



Maybe other ML-based algorithms^[25].

[25] Lars Ivar Hatledal, Filippo Sanfilippo, and Houxiang Zhang. "JIOP: a Java Intelligent Optimisation and Machine Learning Framework". In: *Proc. of the 28th European Conference on Modelling and Simulation (ECMS), Brescia, Italy. 2014*, pp. 101–107.



Legged Robots



[26,27] _____

[26] **Filippo Sanfilippo and Inaki Rano**. “Mimicking the Sense of Smell of Search and Rescue (SAR) Dogs: a Bio-inspired Steering Framework for Quadruped Robots”. In: *Energy* 45 (2023), pp. 128–132.

[27] **Muhammad Hamza Zafar, Even Falkenberg Langås, and Filippo Sanfilippo**. “Real-Time Gesture-Based Control of a Quadruped Robot Using a Stacked Convolutional Bi-Long Short-Term Memory (Bi-LSTM) Neural Network”. In: *2024 10th International Conference on Automation, Robotics and Applications (ICARA)*. IEEE. 2024, pp. 81–86.



Thank you for your attention



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- To know more about my research activity, please visit my website at:
<http://filipposanfilippo.inspitivity.com>.



References I

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References II



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References III

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References IV



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References V



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References VI



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