COMMENTARY

Assistive robots for Beijing Winter Paralympic torch relay: Accessible technologies to restore human functionality

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The success of the Beijing Winter Olympics and Paralympics epitomized the vision of a community with a shared future for humankind. Various robots and artificial intelligence technologies were used in various games and events, such as assisting in parades, logistics, and security inspections. The integration of unmanned robotic systems into torch relays was one of the highlights of the Winter Olympics.[1,2] The first underwater torch relay involving robots in the Olympic Games occurred on February 2, 2022.[1] Similarly, at the PyeongChang Winter Games, the first robotic torch runner was implemented on March 3, 2018.[2] Supported by the National Key R&D Program of China, five types of assistive robots were specially designed for use in the Beijing 2022 Winter Paralympics. These robots are human centered and can be deployed to help restore functionality to meet the needs of people with disabilities.

One important concern was the accessible technologies that are needed for torchbearers. This event was similar to Cybathlon,[3] in which competitors with disabilities performed daily tasks with the support of the latest robotic technologies. Moreover, successful completion of these robot-assisted torch relays was highly anticipated in such an inspiring event, demonstrating the importance of addressing challenges such as device reliability and human-robot interaction (HRI). As Yang et al.[3] cautiously noted, "One big hurdle is whether research findings can be translated into safe, effective, and more importantly, accessible technologies that benefit the population at large."

Another important concern was the demonstration scenario. The trade-off between technical sophistication and public understanding should be considered. Implantable sensors or surgical operations were inappropriate, and care must be taken to avoid controversy in the Paralympics. Considering these issues, the research group proposed a series of robot-assisted torch relay demonstration scenarios, which were approved by the Beijing Winter Olympics Organizing Committee. The scenarios conformed to the Olympic spirit and included placing individuals with disabilities utilizing advanced robotic technologies as focal points in important events.

ASSISTIVE ROBOTS FOR THE TORCH RELAY (trAsBots I–V)

The details of trAsBots I-V are presented in Figure 1. The torch relay occurred on March 2 and 4, 2022, and was reported by China Central Television (CCTV). The following links (I, II, III, and IV) are provided to access related videos.

trAsBot I is a customized exoskeleton for individuals with complete spinal cord injury (SCI) that can facilitate walking. The structural configuration is inspired by humanoid robots, with four active degrees of freedom (DOFs) at the hip and knee joints and two passive DOFs at the ankle joints. The challenge in the control system involves compensating for lower-limb movements and establishing a stable gait pattern.[4] The trajectory was parameterized based on factors such as the stride length, speed, and profile shape. During 1 month of adaptation, these parameters were changed hundreds of times to improve the movement guidance performance and meet the specific application requirements. Based on the sensorimotor system (joint torque sensors and inertial measurement units) and high torque rigid actuators, the optimized gait was determined, allowing the torchbearer to achieve stable walking with crutches and substantially enhance their performance in the 10 m walk test,[5] reducing the time needed from 86 to 52 s.

trAsBot II is an exoskeletal intelligent prosthetic arm that enables active control of both the hand and elbow, representing a new attempt to combine supportive assistance with neural control capability. The robot was developed according to the unique condition of the torchbearer (partial neuromuscular function in the elbow without bone articulation). Thus, the design scheme needed to allow a high degree of integration, with high robustness. trAsBot II has a rigid but hollow structure, with a weight of only 1.5 kg. Due to the weak muscle strength of the residual limb, the load is extremely likely to affect the quality of surface electromyography (sEMG) signals. Based on SeNic, a benchmark dataset containing nonideal sEMG data, a hierarchical control architecture allows for complete functional reconstruction of the residual arm through data monitoring and muscle fatigue supervision.

trAsBot III is another exoskeleton robot designed for individuals with incomplete SCI in the lower extremities that provides movement assistance as walking/rehabilitation orthosis during daily activities. Remarkably, with the training and support of trAsBot III, the torchbearer made gradual progress over 5 years after the initial injury, from initially having difficulty getting out of bed to eventually standing and walking independently. Furthermore, trAsBot III can be applied in the rehabilitation of more than 6 different patient populations (including patients with osteoarthritis, those who have undergone total hip/knee arthroplasty, and individuals with cerebral palsy), with various evidence supporting its efficacy.[5] Incorrect or compromised gait patterns in various outdoor environments (such as ascending/descending stairs and ramps) can be enhanced with movement guidance from the active exoskeleton assistance robot, indicating significant potential for broad future adoption.

trAsBot IV is an intelligent prosthetic hand robot based on a human-robot neural interface that was designed for transradial amputees and provides functional restoration of the hand. The robot is created with 3D printing and injection molding to obtain a personalized receptive cavity. A data-driven model for time-varying myoelectric pattern recognition is utilized to control the robot. With only 1 week of adaptation and integration, the torchbearer achieved natural and volitional control based on sEMG recordings. The reaction time was reduced to 0.8 s, guaranteeing real-time completion of the actions needed for the torch relay. Due to the universality of neural interfaces, this technology was previously used to assist a young girl in collaborating with Mr. Lang Lang, a famous Chinese pianist, to play the piano on the CCTV stage.

trAsBot V is an assistive exoskeleton robot designed for individuals with unilateral lower-extremity neural and muscular impairments that aims to address asymmetric gait patterns in patients with hemiplegia. In the joints, the compliant actuation principle has been utilized to establish a complete kinematic chain in the hip-knee-ankle configuration. A human-robot sensing approach, which combines interaction torque feedback with plantar pressure estimation, enables assist-as-needed assistance, effectively reducing the inconsistencies within and between the bilateral lower limbs[5] through an advanced impedance-based control system. Training experiments were conducted with over 60 patients with hemiplegia, resulting in a reduction in the average bilateral polyarticular asymmetry from 12.6% to 2.1%, and the inter-joint paths were highly similar to the desired template (Pearson correlation coefficient of 0.98). The positive clinical outcomes demonstrate the potential of this robot in mitigating the increasing concerns of older people in China. Due to the health condition of the torchbearer, this robot was not used in the event.

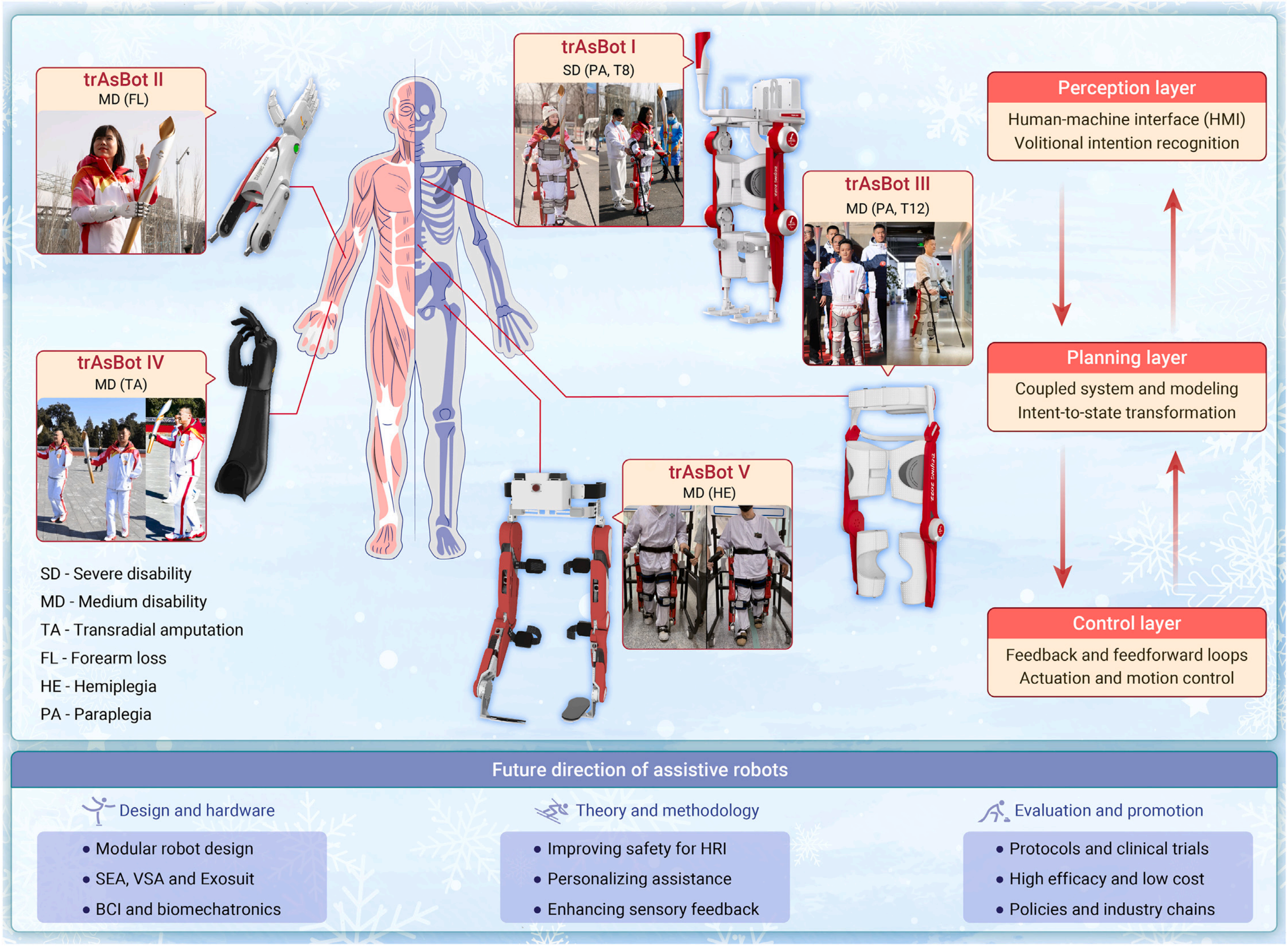

Figure 1. Assistive robots for torch relay (trAsBots I–V) at the Beijing 2022 Winter Paralympics

DESIGN CONCEPT AND HARDWARE TECHNOLOGY

The design principle significantly impacts the implementation of assistive strategies, with modularity playing a pivotal role. Diverse robotic systems have been developed due to the lack of a uniform design consensus, reducing the generalizability of hardware technology. Compliant principles, including series elastic actuators (SEAs), variable stiffness actuators (VSAs), and exosuits,[4] are instrumental in enhancing adaptability and safety for assistive robotics, addressing the gaps due to unexpected biomechanics alterations under external assistance. Additionally, advanced human-machine interfaces (HMIs), such as brain-computer interfaces (BCIs) and bio-machine interfaces, are crucial for enhancing robot intelligence technologies.

ADVANCED THEORY AND METHODOLOGY

For HRIs, safety issues regarding robotics and pattern recognition must be considered. The human-in-the-loop strategies show potential in maintaining a stable perception of the environment while improving the reliability of robot interactions within robust limitations to ensure overall stability. In addition, providing personalized assistance by learning the wearer's biomechanics and personal preferences can reduce dependencies between assistive robots and specific populations, and ultimately facilitate the deployment of accessible technologies. Furthermore, sensory feedback is critical for enhancing cognitive interactions, which involves constructing a natural interaction state to enhance proprioception by reducing the reliance on visual cues and subjective attention to the robot.

TECHNOLOGY TRANSFER AND MARKETING PROMOTION

At present, the use of commercial assistive and rehabilitation robots has rapidly increased, but clinical efficacy, price, and policies are concerns for wider applications. Assistive robots require extensive clinical trials to validate their applicability and safe use as medical devices in healthcare settings. Furthermore, there is an urgent need for cost-effective alternatives that can replace expensive robot hardware, thereby reducing acquisition costs to more affordable levels. Lastly, the continued development of assistive robots relies on policy support for the rehabilitation industry.

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DECLARATION OF INTERESTS

The authors declare no competing interests.