Empowering Robotics With 6G: Connectivity, Intelligence, and Beyond

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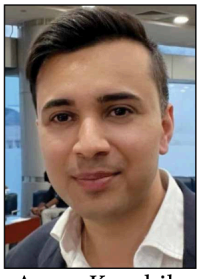

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The convergence of Sixth Generation (6G) wireless technology and advanced robotics is not merely an evolutionary step but a profound, paradigm-shifting fusion. 6G promises to provide the crucial nervous system—characterized by sub-millisecond latency, integrated sensing and communication and native intelligence—that will unleash the full potential of robotics across every sector, from automated manufacturing and smart logistics to remote healthcare and planetary exploration. This special issue, "Empowering Robotics With 6G: Connectivity, Intelligence, and Beyond," is dedicated to capturing this pivotal moment, showcasing groundbreaking research that is forging the essential links between the physical and digital worlds as well as addressing the challenges for human-to-robot and robot-to-robot and robot-to-network interactions.

The central challenge in modern robotics is the trade-off between onboard computational power, energy efficiency, and real-time responsiveness. 6G shatters this limitation. By integrating Hyper-Reliable Low-Latency Communication (HRLLC), centimeter-level sensing and positioning, and distributed edge computing, 6G transforms robots from isolated, semi-autonomous machines into seamlessly connected, intelligent, and collaborative agents. This synergy elevates the impact of robotics from simple automation to true, responsive partnership with human operators and other machines. The practical usefulness is immense: industrial safety improves dramatically with real-time awareness, logistical efficiency soars with coordinated autonomous fleets, and remote medical procedures become feasible with haptic-enabled precision teleoperation.

The seven papers presented in this issue collectively delineate a future where the network itself is an intelligent, flexible resource, actively tailored to the needs of robotic systems. We have categorized these papers into three thematic pillars, showcasing the full scope of requirements needed to guide future standardization efforts.

Foundational Architecture and Standardization of Robot-to-Network Interfaces

This pillar addresses the fundamental requirements for how autonomous agents communicate and how the physical infrastructure must adapt to support dynamic robotic use cases, proposing foundational models for communication and resource integration.

In this article [A1], Chen et al. address the need for standardization and advocates for common data formats and a decentralized architectural model for Simultaneous Localization and Mapping (SLAM) to enable multi-agent collaboration, pointing out that 6G network slicing is the mechanism needed to guarantee Quality of Service (QoS) for both control and mapping data.

Complementing this, Shang et al. [A2] introduce Robotic Aerial Base Stations. This concept demonstrates a potent case of robots *empowering* 6G by transforming them into flexible, deployable, and energy-neutral components of the Radio Access Network, addressing key infrastructure resilience challenges.

AI-Driven Control and Coordination

The second pillar focuses on the advanced AI mechanisms that manage control logic, coordination, and resource allocation across the complex 6G-robotics ecosystem, moving beyond static configurations to dynamic, intent-aware systems.

In this article [A3], Li et al. introduce a paradigm-shifting Generative AI-in-the-Loop framework. The Generative AI agent acts as a high-level cross-domain coordinator, overseeing three interconnected loops: the communication loop, the robot control loop, and the AI model control loop. This approach enables holistic decision-making by interpreting task requirements, network status, and robotic operations, realizing a highly autonomous networked system.

Taming the resulting network complexity is the focus of [A4]. The paper leverages Deep Transfer Learning to manage Radio Resource Management complexity in disaggregated RANs. The authors illustrate how intelligent, adaptive AI is essential for integrating dynamic robotic elements into the network without sacrificing efficiency or performance, leading to an enhanced energy-efficient and scalable robotic environment.

Ensuring Trustworthy and Mission-Critical Autonomy

The final pillar addresses the paramount need for safety, security, integrity, and ethical compliance to ensure these powerful new systems can be safely and responsibly deployed in high-stakes human environments.

In this article [A5], Kanaki et al. address the foundational societal challenges. It conducts a structured ethical assessment of AI-driven robots in 6G environments, analysing key regulatory frameworks like the EU AI Act and GDPR. The paper focuses on safeguarding human rights, dignity, and autonomy while mitigating risks related to data privacy, bias, and accountability, arguing for comprehensive frameworks that ensure trustworthy and ethically aligned systems.

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In this article [A6], Valenzuela et al. highlight the essential role of Network Slicing and Multi-Access Edge Computing (MEC) in enabling safe human-robot co-existence. The authors demonstrate that offloading safety-critical tasks like obstacle avoidance requires prioritizing traffic via slicing, underscoring the non-negotiable requirement for ultra-low latency in mission-critical, shared industrial spaces.

Finally, Bravo-Arrabal et al. [A7] exemplify the trustworthy and mission-critical autonomy pillar by demonstrating, through realistic search-and-rescue deployments, that effective emergency robotics depends on co-designed communication and robotic systems. By integrating hybrid sensing, edge computing, network slicing, and coordinated multi-robot operation, the authors show how resilient connectivity can sustain victim detection, mapping, and casualty extraction even when conventional infrastructure is damaged or absent, outlining a clear path for 5G-Advanced and 6G to strengthen future emergency-response missions.

The papers presented in this special issue provide critical insights into how 6G's transformative capacity is being systematically used to create the next generation of autonomous and collaborative robotic systems and will be as an invaluable resource for researchers, engineers, and policymakers shaping the future of 6G and robotics. This transformative domain is highly active in the global ecosystem, with focused initiatives driving its standardization and practical implementation.

This special issue is endorsed and supported by the one6G Association and its members, aligning with ongoing international ecosystem activities including the IEEE P1955 working group which is a standard project to develop a standard for the integration of robotics with future communication networks. Simultaneously, the one6G Association has a focus on "6G empowering robotics" which produces vital white papers mapping robotic requirements to 6G capabilities. Furthermore, European efforts, spearheaded by organizations like euRobotics, actively shape the Connected Robotics Topics Group, ensuring that foundational research is translated into societal and industrial advantage.

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Appendix: Related Articles

[A1] H. Chen, A. Hussain, E. Meziane, P. Chatzimisios, S. Oteafy, J. Lee, B. Nguyen, S. Saeedi, and H. Li, "Toward 6G-enabled robots—A case study of cooperative multi-quadrotor 3-D mapping," *IEEE Commun. Standards Mag.*, vol. 10, no. 2, pp. 254–262, Jun. 2026, doi: 10.1109/MCOMSTD.2025.3632897.

[A2] W. Shang, Y. Liao, V. Friderikos, and H. Yanikomeroglu, "Anchor-and-connect: Robotic aerial base stations transforming 6G infrastructure," *IEEE Commun. Standards Mag.*, vol. 10, no. 2, pp. 263–270, Jun. 2026, doi: 10.1109/MCOMSTD.2025.3630439.

[A3] P. Li, X. Lin, and A. Aijaz, "Rethinking networked robotics in the 6G era with generative AI-in-the-loop," *IEEE Commun. Standards Mag.*, vol. 10, no. 2, pp. 287–295, Jun. 2026, doi: 10.1109/MCOMSTD.2025.3620856.

[A4] S. Wang, S. Zaidi, M. Hafeez, L. Zhang, and M. Tatipamula, "Deep transfer learning in 6G networks: A greener approach for taming the complexity," *IEEE Commun. Standards Mag.*, vol. 10, no. 2, pp. 271–279, Jun. 2026, doi: 10.1109/MCOMSTD.2025.3633065.

[A5] E. Kanaki, A. Hessami, P. Gonçalves, and P. Chatzimisios, "Ethical and privacy issues for AI in 6G empowering robotics," *IEEE Commun. Standards Mag.*, vol. 10, no. 2, pp. 296–304, Jun. 2026, doi: 10.1109/MCOMSTD.2026.3658562.

[A6] A. M. Valenzuela, J. V. Pérez, J. S. Blanes, and V. S. Payá, "Evaluation of combined network slicing and MEC toward mobile robot applications in 5G networks," *IEEE Commun. Standards Mag.*, vol. 10, no. 2, pp. 280–286, Jun. 2026, doi: 10.1109/MCOMSTD.2025.3633077.

[A7] J. Bravo-Arrabal, R. Vázquez-Martín, J. J. Fernández-Lozano, and A. García-Cerezo, "Strengthening multi-robot systems for search and rescue: Co-designing robotics and communications towards 6G," *IEEE Commun. Standards Mag.*, vol. 10, no. 2, pp. 305–312, Jun. 2026, doi: 10.1109/MCOMSTD.2026.3678471.

Biographies

Mona Ghassemian is a Principal Expert working with Huawei and a Visiting Fellow at King's College London, with over 25 years' experience shaping 6G strategy, architecture, and standards for robotics and automation. She has held senior roles including Senior Manager of a standardization team at InterDigital and Principal Scientist at BT Group, alongside academic appointments as Assistant and Associate Professor at KCL and University of Greenwich. She chairs the IEEE P1955 and is Lead Guest Editor of this special issue.

Kaspar Althoefer is a Professor of robotics at Queen Mary University of London, U.K., and the Director of the Centre for Advanced Robotics. With over 30 years of experience, his research focuses on soft robotic systems, intelligent manipulation, and AI for sensor interpretation in healthcare. He was the General Chair of ICRA 2022 in London. Highly active in the 6G-robotics nexus, he led and presented the one6G White Paper on 6G Empowering Future Robotics at several events.

Aryan Kaushik is CEO at OUF Innovative, CIO at RakFort, and Adjunct Professor at IIITD. Previously, he was with Manchester Met, the University of Sussex, and UCL, with affiliations across Europe and Asia. A Stanford/Elsevier Top 2% Scientist, he serves in IEEE leadership roles, proposal evaluator for EPSRC, Editor of journals including IEEE Transactions on Mobile Computing and books, and delivered more than 140 invited talks while chairing at major conferences and workshops such as IEEE ICC and IEEE GLOBECOM. He is the Vice Chair of WG3 of the one6G Association.

Mahdi Tavakoli is a Professor of electrical and computer engineering and the Director of the Telerobotic and Biorobotic Systems Lab, University of Alberta, Canada. His research interests include haptics, shared autonomy, and robot-assisted surgery. He explores the crucial role of 6G in delivering the ultra-low latency and high-fidelity, real-time feedback required for effective teleoperation, directly pushing the boundaries of the Tactile Internet and remote control of complex robotic systems.

Douwe Dresscher worked as a postdoc and later as a tenured professor at the University of Twente (UT), focusing on telemanipulation and robotic avatar systems. He shaped collaboration between UT and TNO in the i-Botics joint innovation centre. Douwe led efforts in the ANA Avatar XPRIZE competition, where they placed in the top five. In 2022, he founded Avatars. Report to broaden access to knowledge and technology in robotic avatars.

Xueli An is a Principal Expert and the Head of 6G Network Architecture Research Group, Huawei Technologies, Germany. Her work investigates AI-native architecture design and automation, driving the crucial convergence of 6G and robotics towards future intelligent systems. She is highly active in standardization, serving as the Vice Chair of the 5G-ACIA Working Group "Use Cases and Requirements," the Chair of the one6G Association Working Groups on "Communication and Dissemination," and the Vice-Chair of NetworldEurope's Enabling Technologies Working Group.