Chasing a Dream:
The Quest for Minsky's Concept of Telepresence

IEEE Telepresence Initiative White Paper

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Introduction

You don a comfortable jacket lined with sensors and muscle-like motors. Each motion of your arm, hand, and fingers is reproduced at another place by mobile, mechanical hands. Light, dexterous, and strong, these hands have their own sensors through which you see and feel what is happening. Using this instrument, you can "work" in another room, in another city, in another country, or on another planet. Your remote presence possesses the strength of a giant or the delicacy of a surgeon. Heat or pain is translated into informative but tolerable sensation. Your dangerous job becomes safe and pleasant.[1]

The term 'telepresence' was popularized following its use in a 1980 article written by Marvin Minsky[2], MIT professor and pioneer in artificial intelligence[3]. Aptly, the article was published in a popular science fiction magazine at the time, *Omni*, as it is often within fiction that we envision the technology systems of the future. Minsky's vision described a "remote-controlled" society fueled by the development of advanced robotic systems that could be used in medicine, manufacturing, and other areas of work.[4] He imagined a future where flexible wearable "sensors" and "dexterous" robotic hands provide the user with the sensation of work at a distance, and where one's "robotic presence possesses the strength of a giant or the delicacy of a surgeon."[5] He envisioned a world encompassing the human desire to explore space and the deep seas, as well as navigating the reality of a complex society with many hazards, including the then-recent nuclear disaster in 1979 at Three Mile Island[6], devastating oil spills, and international conflicts.

In 2010, *IEEE Spectrum* republished Minsky's article, noting that his "manifesto remains as current and compelling as ever, a powerful call for technology that could bring about huge societal benefits."[7] Telepresence has the proven potential to make meaningful impacts in areas such as space exploration, education, healthcare, and safety. As we stand at the cusp of the 45th anniversary of Minsky's original publication, how close are we to realizing the future he imagined?

Understanding telepresence

Minksy made clear in his essay that he preferred the term *telepresence* over others because "it emphasizes the importance of high-quality sensory feedback and suggests future instruments

[1] https://web.mit.edu/dxh/www/marvin/web.media.mit.edu/~minsky/papers/Telepresence.html
[2] https://www.nytimes.com/2016/01/26/business/marvin-minsky-pioneer-in-artificial-intelligence-dies-at-88.html#
[3] Minsky credited the term to his friend and fellow futurist, Patrick Gunkel.
[4] https://spectrum.ieee.org/telepresence-a-manifesto
[5] https://web.mit.edu/dxh/www/marvin/web.media.mit.edu/~minsky/papers/Telepresence.html
[6] https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html
[7] https://spectrum.ieee.org/telepresence-a-manifesto

that will feel and work so much like our own hands." He noted that telepresence was not "science fiction"—even though "the crude robotic machines" at the time of his writing were limited in function, he believed that with targeted investment, telepresence could be realized in 10 to 20 years, at the turn of the twenty-first century.[8]

Following the publication of his manifesto, the idea of achieving telepresence spurred innovative attempts to develop telepresence-related technology, including the projection of holographic humans mimicking those seen in popular movies[9] as well as robotic avatars that serve in place of one's actual body at a distant location[10]. Early prototypes offered the initial promise of turning Minsky's dream into reality and fundamentally changing the ways in which we connect to and interact with each other. Yet, the future Minsky envisioned remains elusive.

A key inhibitor has been that many of the system requirements for telepresence on the scale Minsky described are still under development. Telepresence is a complex field, requiring knowledge and technology from robotics, extended reality, system networks, human-computer interaction, neuroscience, psychology, and artificial intelligence. Since 1980, multiple advances in these areas established the foundation of telepresence systems in varying degrees, but several challenges exist.

Minksy himself noted that "the biggest challenge to developing telepresence is achieving that sense of 'being there'." That is, systems that allow us to physically interact with remote environments and people in real-time, transporting one's senses, skills, and presence to any place in an instant. Only recently have we begun to achieve the level of advanced robotic platforms and multisensory human interface techniques which together can provide that sense "of being at another location than one's physical body,"[11] and the field is now posed to make significant leaps.

At this time, coordinated and collaborative efforts are vital to move the field forward. The IEEE Future Directions Telepresence Initiative was launched in 2021 to facilitate such coordination, including the development of a technology roadmap to help guide the research community and communicate the challenges to stakeholders in industry and government. This white paper serves as the first step in the process by outlining the current state of the technology and near- to mid-term challenges. Forming coalitions of key stakeholders, promoting the value of telepresence technology, and identifying requirements for growth are essential steps in preparing for the future of telepresence.

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[8] https://web.mit.edu/dxh/www/marvin/web.media.mit.edu/~minsky/papers/Telepresence.html

[9] https://www.nbcnews.com/mach/science/futuristic-hologram-tech-promises-ultra-realistic-human-telepresence-ncna871526

[10] https://www.youtube.com/watch?v=mZ22wi-nyfg

[11] https://ris.utwente.nl/ws/portalfiles/portal/293579847/What_Comes_After.pdf

Telepresence landscape

A genuine telepresence system requires new ways to sense the various motions of a person's hands. This means new motors, sensors, and lightweight actuators. Prototypes will be complex, but as designs mature, much of that complexity will move from hardware to easily copied computer software. The first ten years of telepresence research will see the development of basic instruments: geometry, mechanics, sensors, effectors, and control theory and its human interface. During the second decade we will work to make the instruments rugged, reliable, and natural.[12]

Over the past 45 years, telepresence technologies made steady progress in phases of development (see Figure 1). Advancements in remote capabilities—including in telecommunications and telerobotics—enhanced operator experience to include some sense of being in another location. That is, the use of sophisticated video cameras and microphones provided the opportunity to co-locate and experience limited interaction with people and/or the environment in a distant (real or imagined) location. Examples of this include teleconferencing, drone control, and remote operation of machinery.

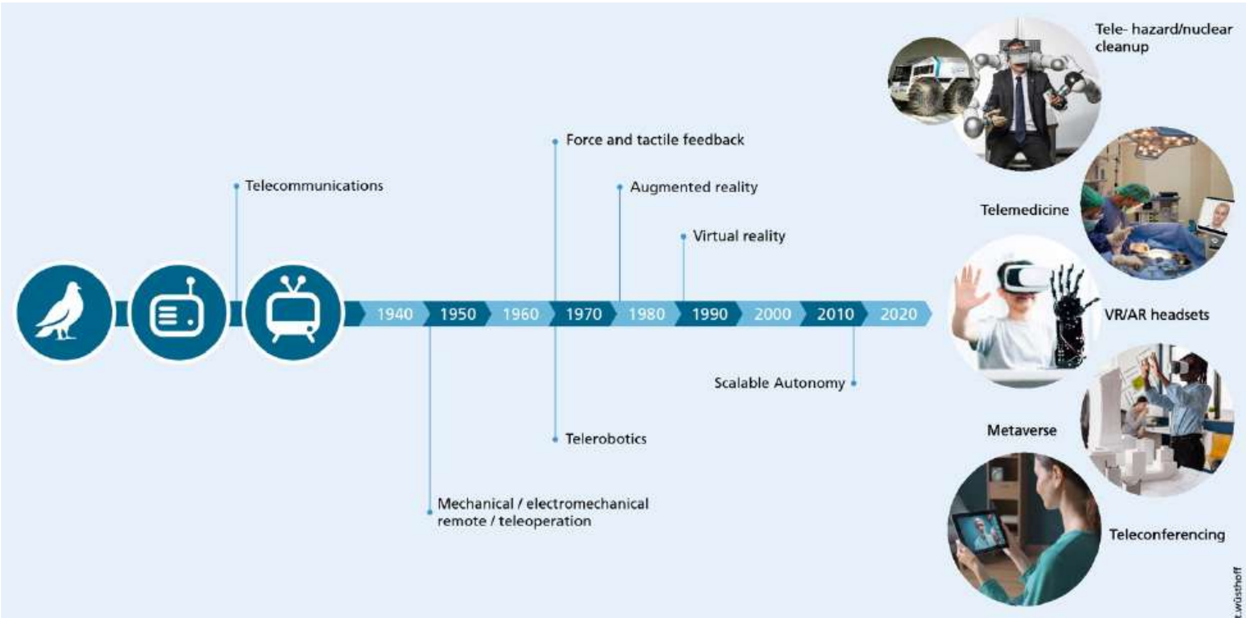

Figure 1: Initial telepresence technology sets the stage for an integration of early telecommunication systems with more advanced telerobotics and teleoperation applications.

There are distinctions, however, between what might be considered telepresence as opposed to remote operation, or teleoperation. Sophisticated telepresence requires not only robotic sensing and actuation, but also high-performance communications, effective user interfaces, and thoughtful deployments that take the user's broader contexts into account.

[12] https://web.mit.edu/dxh/www/marvin/web.media.mit.edu/~minsky/papers/Telepresence.html

In efforts to enhance user interfaces, 3D headsets emerged in the early 1990s with the development of virtual arcade machines that provided new immersive experiences for multiplayer games.[13] The second decade of the twenty-first century saw particular growth in this area, with the launch of the Oculus Rift in 2010, followed by multiple commercial development projects. These systems enabled the user to participate in an imagined world; however, Minsky's goal of more sophisticated telepresence was to focus on the real world, emphasizing a first-person perspective and allowing for interaction with that location's environment and other participants.

By 2019, the majority of commercial 3D headsets moved from tethered to "standalone" along with quality advancements that enabled users to engage with their environment in new ways. The cautionary tale in this arena was the failure of Google Glass[14], launched in 2013. A key feature of Google Glass was the capacity to project information with images and text on the real world seen by the user. This augmented reality (AR) provided a user experience that combined the real and the virtual. Although technically advanced, the device did not adequately address consumers' privacy and usability concerns and was eventually withdrawn from the market. Even so, development of virtual (VR) and augmented reality headsets continued, and systems are now readily available at a consumer price point. Examples include the Meta Quest[15] and the Apple Vision Pro[16], which offer a fully immersible, spatial experience that aims to modify interaction in both home and work environments. Used on a different user interface—the mobile phone—AR has successfully reached the general population with games such as *Pokemon Go* (2016), which places game characters in real surroundings for a network of players worldwide.

Until recently, however, user interaction has been limited in scope and feedback due to constraints in sensing and feedback technology, particularly in haptic feedback areas[17]. These technologies[18,19] began appearing in the 1990s and early 2000s, with restricted capabilities at high cost. Even as haptic suits[20] and gloves[21] with tactile feedback are becoming more sophisticated, these often remain high cost and difficult to use beyond controlled environments. Many of these are marketed for entertainment, i.e., gaming, in tandem with VR headsets; use of haptic equipment in other areas is anticipated[22] and emerging[23].

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[13] https://aimagazine.com/articles/the-1960s-to-the-vr-revolution-the-history-of-vr-headsets
[14] https://www.healthcare.digital/single-post/why-did-google-glass-fail-in-healthcare-and-overall-with-consumers
[15] https://www.meta.com/quest/quest-3/
[16] https://www.apple.com/apple-vision-pro/
[17] https://www.youtube.com/watch?v=x6ewRfchPSA
[18] http://www.forcedimension.com/
[19] http://www.cyberglovesystems.com/cybergrasp
[20] https://www.bhaptics.com/en/
[21] https://senso.me
[22] https://senso.me/tpost/9mo0t4p8l1-senso-glove-in-medicine-and-rehabilitati
[23] https://haptx.com

Recent competitions such as the ANA Avatar XPRIZE[24] have driven innovation and spurred remarkable advances with robotic avatars[25]. These include systems that "facilitate the embodiment of humanoid robots by human operators encompassing aspects such as locomotion, manipulation, voice, and facial expressions with comprehensive sensory feedback including visual, auditory, haptic, and touch modalities."[26] Such comprehensive systems might be used in healthcare ecosystems for patient care, as well as in extreme environments where access is difficult for humans due to dangerous conditions or remoteness—including the ocean floor or outer space. Ultimately, they also may be used to enhance social interaction over a distance, allowing for interpersonal communications, participation in education and training opportunities, and other educational or tourism ventures.

Another important area of growth has been in scalable autonomy, where a combination of artificial and human intelligence work together to control robotic systems.[27] Even as robotic systems become more complex and able to perform certain functions autonomously, expert supervision is still required. The desire for involvement on behalf of the user is also a factor when exploring ways to successfully integrate artificial intelligence and human input into a harmonious system, which remains a fundamental challenge.

Overall, the field has reached a stage where a high level of social interaction and task completion can be demonstrated. Essentially, the technology components are available—the next-generation devices are in research and design laboratories today. However, the ability to implement and scale these technologies for widespread adoption in multiple ecosystems remains a future target.

Telepresence ecosystems

Minsky envisioned the use of telepresence systems in key areas such as mining (land and sea), maintenance and fabrication, construction and operations in outer space, elimination of chemical hazards, nuclear power generation, and medical and surgical applications.[28] Today, many of these ecosystems, as well as others, are in the process of employing or are posed to employ telepresence systems. Early prototypes have shown promise for continuous interaction and service when employing multiple operators, along with the opportunity to deploy multiple skill sets, provide specialized services in remote locations, and more.

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24 https://www.xprize.org/prizes/avatar

25 https://www.senseglove.com/ana-avatar-xprize-winners-team-nimbro-revolutionizes-human-robot-interaction-using-the-senseglove-dk1/#:~:text=Team%20NimbRo's%20Victory%20at%20ANA,XPRIZE%20on%20Novemeber%205th%202022.

26 https://techxplore.com/news/2024-01-humanoid-robots-labs-evolution-fully.html#google_vignette

27 https://www2.whoi.edu/site/marinerobotics/research-portfolio/co-robotics-scalable-autonomy-and-adaptive-sampling/

28 https://web.mit.edu/dxh/www/marvin/web.media.mit.edu/~minsky/papers/Telepresence.html

The value and requirements of such systems for researchers, developers, corporations, governmental entities and organizations, and users (in both the workplace and for recreational purposes)[29] vary based on specific needs and outcomes. Highlighted below is a list of strategic development areas and ways in which telepresence can provide significant value for diverse ecosystems.

Extreme Environments

Key Areas: space exploration, space infrastructure construction and maintenance, deep sea exploration, disaster recovery, nuclear and other hazardous environments

Outer space[30] and deep-sea explorations[31] are inherently costly, difficult, and risky. Telepresence systems that enable high-fidelity remote human presence have the potential to significantly reduce crew risk, increase mission capacity (e.g., greater number of Extra-Vehicular Activity hours), and improve scientific return.[32,33] Increasing robot autonomy in combination with advancements in haptic feedback under time-delays can help overcome the inherent latencies and less dependable communication, allowing for an immersive interface and new operational capabilities, e.g., maintenance and repair, construction, assembly, field geology, and surface surveys. [34,35] This ability to go from immersive interaction with the robots as avatars to intelligent coworkers on-site, gives a new dimension to telepresence with scalable autonomy.[36,37] In addition, the deployment of telepresence systems in hazardous environments decreases human risk and aids in research and recovery.[38]

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[29] This white paper is aimed at individual researchers and users in the general public. Most, if not all, would directly or indirectly connect to several ecosystems and organizations.

[30] https://www.sciencedirect.com/science/article/pii/S001910352100230X

[31] https://oceanexplorer.noaa.gov/technology/telepresence/telepresence.html; https://www.hydro-international.com/content/article/telepresence-technology

[32] Anderson, R., Adamo, D., Jones, T., and Podnar, G. (eds). 2020. Space Science Opportunities Augmented by Exploration Telepresence, W.M. Keck Institute for Space Studies.

[33] Fong, T., Zumbado, J., Currie, N., Mishkin, A., Akin, D. 2013. Space Telerobotics: Unique Challenges to Human-Robot Collaboration in Space. Reviews of Human Factors and Ergonomics 9(6).

[34] https://robohub.org/how-do-we-control-robots-on-the-moon/

[35] https://news.stanford.edu/stories/2022/07/oceanonek-connects-humans-sight-touch-deep-sea

[36] Lii, N.Y., Riecke, C. Leidner, D., Schätzle, S., Schmaus, P., Weber, B., Krueger, T., Stelzer, M., Wedler, A., and Grunwald, G., 2018. The Robot as an Avatar or Co-worker? An Investigation of the Different Teleoperation Modalities through the KONTUR-2 and METERON SUPVIS Justin Space Telerobotic Missions. International Astronautical Congress

[37] Lii, N.Y., Schmaus, P., Leidner, D., Krueger, T., Grenouilleau, J., et. Al., 2022. Introduction to Surface Avatar: the First Heterogeneous Robotic Team to be Commanded with Scalable Autonomy from the ISS. International Astronautical Congress

[38] https://www.inceptivemind.com/new-robot-set-help-people-hazardous-environment-research/19322/

Healthcare
Key Areas: patient care, rehabilitation, therapy, diagnosis, telesurgery, device maintenance

Telepresence has the potential to revolutionize healthcare, allowing physicians and caregivers to provide aid remotely, as well as enabling medical students to obtain training from experts around the world or explore and interact with remote medical activities. Robotic telepresence for remote caregiving is being explored for supporting older adults[39] and those with special needs[40]. Patient care in hospitals, both in the emergency room[41] and recovery rooms[42], can be enhanced by telepresence monitoring systems, improving access to healthcare services, even for those in remote locations[43]. Telepresence may also provide doctors with additional cues to better perform examinations and remote diagnoses, as well as provide patients with access to remote therapy sessions.

Education and Training
Key Areas: tele-education, medical training

Remote education via telepresence allows easier and better access for many students while utilizing many bi-directional communication channels.[44] Active participation requires students to fully control where they engage and focus, to seamlessly collaborate and socially interact with peers and teachers, and to be seen on white boards or in discussions; they must be present in the classroom, not just passive observers of videos.[45] Telepresence also allows students to feel immersed in different countries, thus boosting their learning experiences, or at heritage sites, engaging with rare artifacts. Training of ship/aircraft engineers, gaining experience with critical situations, or even pilots gaining experience with unsafe flying conditions, are projected benefits of using telepresence.

Industrial and Maintenance Applications
Key Areas: remote equipment maintenance, customer service, security

Some examples in enterprise and industrial environments are mobile telepresence for remote inspection, cleaning, maintenance, customer service, and security[46]. Regardless of the quality of the platform autonomy, telepresence technologies for remote operation/support are necessary

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[39] https://geriatronics.mirmi.tum.de/en/garmi/
https://www.tum.de/en/news-and-events/all-news/press-releases/details/garmi-care-robot-becomes-a-universal-assistant

[40] https://www.dlr.de/en/rm/research/projects/completed-projects/smile-project

[41] https://cseweb.ucsd.edu/~smatsumo/HRIPioneers2024_matsumoto.pdf

[42] https://www.youtube.com/watch?v=EpS6ouacwnU
https://www.youtube.com/watch?v=A5q20jBiIA0

[43] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10837455/

[44] https://dl.acm.org/doi/10.1145/3663384.3663394

[45] https://ieeexplore.ieee.org/abstract/document/8172377

[46] https://www.cobaltai.com

components for operating commercial fleets and remote industrial sites with high reliability. One particularly compelling enterprise and industrial application is focused on bringing remote expertise to a place that needs it, thereby addressing pain points of labor shortage and access to specific trades and skills. Telepresence robotics are already used for remote forklift operators[47] and security guards to minimize harm and provide wider capabilities. These systems can also be useful for providing access to remote sites, including manufacturing facilities, construction sites, etc.

Enterprise and Workplace

Key Areas: communication, tele-conferencing

More recent promising developments for telepresence technology concern mediated social interaction beyond current video-conferencing platforms[48]. Remote users need a stronger agency to be able to change their view, move about in the world, manipulate the world, gesture, and generally act and communicate with more than just their voice. This may include control over physical embodiments, social touch, and proximity, as well as other nonverbal communicative gestures.

Consumer Applications

Key Areas: communication, entertainment/gaming, health and wellness, tourism

Some examples of consumer telepresence robotics applications include keeping in touch with friends and extended family members[49]—particularly with distant relatives—shopping together,[50] and playing together. There are also many opportunities to use telepresence robots to enable older adults to experience places that have become difficult for them to reach (e.g., sporting events, concerts, outdoor hikes)[51]. In tandem, robotic avatars enable others with difficulties navigating social interactions to participate in social interactions, such as the robot café created by OryLab Inc.[52] E-commerce is another area that would benefit from telepresence capabilities. The growing desire for immersive gaming and fitness experiences[53] is helping to drive the field forward in both visual and haptic areas.

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47 https://www.thirdwave.ai

48 https://gobe.blue-ocean-robotics.com
https://www.avarobotics.com

49 https://dl.acm.org/doi/abs/10.1145/3274459

50 https://dl.acm.org/doi/abs/10.1145/3274460

51 https://dl.acm.org/doi/abs/10.1145/1957656.1957665

52 https://dawn2021.orylab.com/en/

53 https://www.wust.edu/post/how-vr-and-ar-have-changed-gaming

Technology challenges

[Telepresence] requires imaginative specialists in sensors, effectors, control theory, artificial intelligence, software, engineering, psychology, and first-class facilities for mechanical and electrical engineering and materials science. It will need strong resources for interactive computation and for real-time physical simulation. … I can't imagine anyone doubting that telepresence is possible. It's a matter of solving many problems that are hard, but not impossible.[54]

Many challenges still need to be addressed if we are ever going to realize next-generation telepresence. Currently, artificial intelligence (AI) and autonomy solutions are not at levels required for advanced deployment, particularly when dexterity is required or when dealing with unknown situations, conditions, and environments. As a result, human input is still needed, as are methods for introducing expert knowledge into robotic systems.

General system advances required for widespread use would likely include at minimum:

- Increased efficiency and efficacy,
- Enhanced sensory control and feedback,
- Ease of mobility,
- Safety at all levels,
- Data security,
- Device design grounded in ease-of-use and ergonomics best practices,
- Reliability, especially in extreme and hazardous environments.

In addition, the following design aspects are needed for fully functioning, next generation telepresence systems. Key terms have been defined with specific targets, and current state as well as required evolutionary steps are noted (see Table 1).

Table 1: Areas of Telepresence Technology Challenges

Requirement	Definition	Target	Example
Configurability	The ability of the system to perform a variety of tasks by easy re-programming or physical alteration	Tailor-made, plug and play configuration	The system can easily be configured to be used in different ways (e.g., slow motion vs. full speed) by different people (e.g., new users vs. advanced users)
Adaptability	The ability of the system to adapt to different work scenarios,	Real time adaptation to human-state, task, environment, network connection	The system adapts its behavior to object properties or

[54] https://web.mit.edu/dxh/www/marvin/web.media.mit.edu/~minsky/papers/Telepresence.html

	environments, conditions, and users		bandwidth changes in real time
Interaction	The ability of the system to interact socially, cognitively, and physically with the user(s) of the system (direct stakeholders), the environment, and the other people in the environment (indirect stakeholders)	Natural bidirectional (functional and social) interaction as if being there	Social interaction with remotely located individuals including bidirectional exchange of (non-verbal) social cues, including “transparent robotic avatar”, i.e., the local people interact with the operator and not the robotic avatar as entity
Manipulation	The ability of the system to perform dexterous tasks	Intuitive, dexterous manipulation of arms and end effectors	Head-following sensor control, arm and hand tracking to control end effectors, body tracking for avatar posture, legs/feet tracking to control avatar locomotion, and physiological sensors to control variable stiffness of limbs
Perception	The ability of the system to perceive the human intention of the operator, the environment (threats, mass, and size of objects recognition of obstacles), and people in the environment	Immersive, multisensory operator feedback	Isolate the operator from his/her physical location while providing multisensory (visual, haptic, auditory, olfactory, temperature, etc.) stimuli representing the remote environment, creating the perception of being in the remote environment
Cognition	The ability to interpret the task and environment such that tasks can be effectively/efficiently executed even with environmental or task uncertainty; ability to distinguish motion	Fluent blending of local AI and autonomy with operator control	The robotic system seamlessly supports the operator and the human operator supervises local autonomy; shared autonomy; scalable autonomy; filter/select/process

	caused by perturbations from those by intention		sensor data to information (also semantic) for the user for optimal task completion
Dependability	The ability of the system to perform its given tasks without error	Performance in same degree of dependability as that of a local operator	The robotic system reliably performs in expected ways without constant intervention from robot wrangler
Locomotion	The ability to move and reach difficult places	Moves in same manner as that of a local operator	The robotic system moves through the physical environment in ways that are consistent with the intentions of the local operator (motion trajectories)
Operational and Social Embedding	The ability to implement and operate the system in an efficient, accepted, safe, and healthy way	Efficient, accepted, safe, and healthy system	Has economic value, is well-trusted, socially and ethically responsible; systems promote well-being and job quality and do not cause detrimental physical or mental health effects; are safe-by-design, the ability to perform a task effectively without harming itself, the operator, its environment, and the people in it

It is also imperative that regulatory guidelines be better adapted for the inclusion and certification of telepresence systems, particularly in healthcare ecosystems. Investment strategies also need to be further refined for wide-scale adoption.

Framing telepresence

An initial framework for considering key structures in telepresence development was established by the IEEE Telepresence Initiative in 2022 and expanded and improved in 2023.[55]

[55] https://telepresence.ieee.org/events/on-demand-recording-smc2023

This framework takes three perspectives as main pillars: 1) Task, 2) System, and 3) Human Factors (Figure 2, left panel). The more recent version includes "perspectives" in technology areas (Figure 2, right panel), and the introduction of generic telepresence system abilities as well as areas of broader context, i.e., embedding.

In this framework, the Task perspective concerns application and business considerations, including the ways in which telepresence technology will be useful for society. Topics addressed include barriers to entry, cost and access, infrastructure, security, adoption, market sizes, and performance evaluation.

The System perspective concerns technologies, including hardware, software, and algorithms. Technologies required for telepresence systems include sensors, networks, intuitive displays, multi-modal user interfaces, dexterous end effectors, power (e.g., batteries), robotic avatars, artificial intelligence, and the means for increasing levels of autonomy.

Lastly, the Human perspective concerns user perception and experience, including identification of how people perceive telepresence technologies and the ways in which these perceptions guide technology development and applications. Topics in this area include multisensory perception, cognition, and experience (including vision, auditory, touch, olfaction, taste, temperature, proprioception, etc.); skill transfer; training; usability; well-being; job quality; privacy and consent; and concepts such as telepresence immersion, social connection, and embodiment.

This framework serves an organizing methodology for examining the nuances and depth of the telepresence field to assist in the development of a technology roadmap.

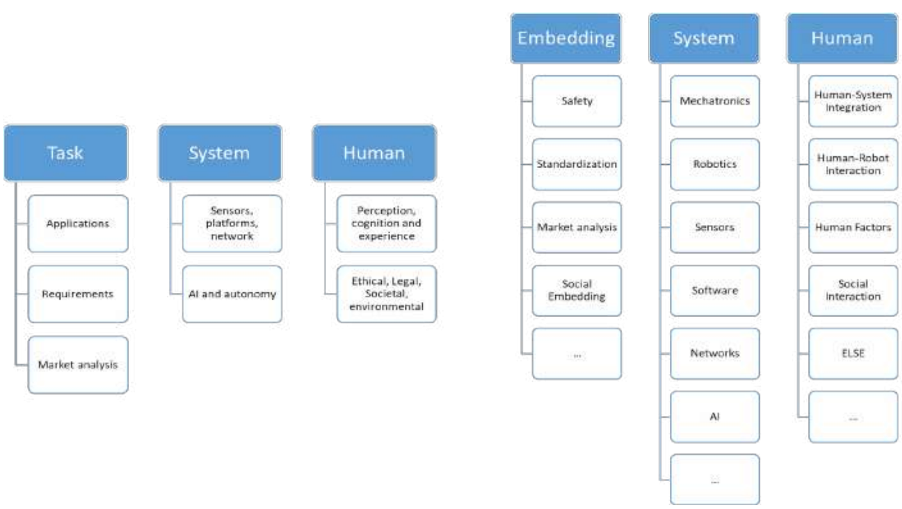

Figure 2. The framework for the IEEE Telepresence Roadmap has three distinct pillars or perspectives: Task, System, and Human (left panel) that link to three major technology areas and their sub-technologies: Embedding, System, and sHuman (right panel).

The call for action

Nearly forty-five years after the publication of Minsky's essay, the field of telepresence continues to entice with possibilities for transforming multiple aspects of society and human interaction. Establishing key structures and realms within the telepresence field and identifying current challenges is imperative in helping the field flourish. Building on the initial framework outlined above, the IEEE Telepresence Initiative is looking to actively engage key stakeholders in collaborative discussions addressing technology challenges, regulatory challenges, and obstacles to the creation and adoption of next-generation telepresence systems. Together, we can map the pathway to the future Minsky established many years ago.

For more information and to get involved in this important effort, see https://telepresence.ieee.org. To provide feedback on this white paper, please email comments to telepresence@ieee.org.