Some recent science fiction movies, most notably James Cameron’s Avatar (2009) or Jonathan Mostow’s Surrogates (2009), portray what could possibly be regarded as the ultimate telepresence system, whereby people are remotely embodied in surrogate robotic bodies. The users of these systems control these representations as naturally as they control their own bodies, and experience the world through sensors mounted on these remote representations. At the same time that Hollywood was producing such fantasy movies (and with a fraction of the budget!), the scientific and technological communities have been making impressive progress in realizing such scenarios in practice, with the goals of helping disabled people and advancing the possibilities of telepresence.

Such tele-embodiment scenarios pose two major challenges, each of which is both scientific and technological. The first is the science and technology of embodiment. The scientific question is: how does our brain represent our own body? Research in the last few years has shown that this representation is rich yet flexible; for example, there has been a wealth of neuroscientific studies on the rubber arm illusion (Botvinick & Cohen, 1998; Ehrsson, Spence, & Passingham, 2004) and many variations were reconstructed in virtual reality (Banakou, Groten, & Slater, 2013; Kilteni, Normand, Sanchez-Vives, & Slater, 2012; Slater, Perez-Marcos, Ehrsson, & Sanchez-Vives, 2008). Moreover, there has been research extending this arm illusion to the illusion of controlling a whole remote body (Ehrsson, 2007; Slater, Marcos, Ehrsson, & Sanchez, 2009).

The second breakthrough is required in brain–computer interfaces (BCIs)—the science and technology of controlling remote devices “by thought.” Early work with BCIs focused largely on fundamental issues such as developing and validating simple BCI spellers in field settings, especially with patients (Wolpaw, Birbaumer, McFarland, Pfurtscheller, & Vaughan, 2002). However, the last several years have seen huge improvements in BCI performance and flexibility, including an emerging interest in combining BCIs with virtual reality (VR) and robotics (Allison et al., 2012; Pfurtscheller et al., 2006; J. Wolpaw & E. W. Wolpaw, 2012) and even controlling avatar and humanoid robotic representations using BCI (Bell, Shenoy, Chalodhorn, & Rao, 2008; Cohen, Koppel, Malach, & Friedman, 2014; Friedman et al., 2007; Kapeller et al., 2013). These developments have created a myriad of new research questions. Which types of brain imaging methods can be used for such BCI control? Which mental activities can people use to direct an avatar or robot with a BCI? How can these mental activities best be mapped to control different actions, such as movements or gestures? Do users experience a strong sense of immersion, presence and/or ownership of a surrogate (virtual or robotic) body? How does BCI performance when controlling such surrogate bodies compare with other control methods?

This special section of Presence devoted to robots, virtual reality, and brain–computer interfaces in telepresence presents three papers that address these two themes, separately or in conjunction. Notably, these articles assessed both objective measures such as task completion time and subjective measures (via questionnaires) that evaluated subjects’ feelings of ownership, embodiment, presence or control with these novel interaction environments. Subjects were generally able to effect real-time control, and felt a strong sense of immersion in different tasks, even when controlling a surrogate body in another country.

Indeed, these three articles also show the breadth of this emerging research interaction. Authors of these three articles come from Austria, Italy, Israel, Spain, France and Japan. The authors include top experts from commercial and academic sectors and from different disciplines, including neurobiology, VR programming,
communications, robotics and BCI hardware and software engineering. The articles utilize numerous devices such as humanoid robots, different BCI imaging methods (fMRI and EEG), head-mounted display (HMD), tools for visual feedback, an eye tracker, galvanic skin response (GSR) and respiration sensors, a mobile platform and proprioceptive feedback systems. The articles also present many of the broad and fertile research opportunities in the near future. This introduction summarizes each article, followed by a brief conclusion.

The first article, titled “fMRI-Based Robotic Embodiment: Controlling a Humanoid Robot by Thought Using Real-Time fMRI,” presents four subjects who tried to control a humanoid robot with an immersive BCI approach. Cohen and colleagues describe a real-time fMRI system that can detect subjects’ imagination of left hand, right hand, or foot movement. Subjects in Israel could direct a robot in France to perform corresponding movements (move left, right, or forward) by sending data over a UDP connection. These BCI users could observe the remote location using a camera mounted on the robot and see their point of view changing in real time in response to mental commands. Subjects were asked to navigate around obstacles and move toward one of three doors presented in a virtual room. Furthermore, the article explored differences in brain activation during imagined versus real movements. Questionnaires provided subjective feedback; for example, one subject provided anecdotal comments indicating a strong sense of immersion. The authors intend follow-up work to further enhance control and the sense of presence, with additional commands and exploration of embodiment with BCIs.

The second article, from Kishore and colleagues, presents a “Comparison of SSVEP BCI and Eye Tracking for Controlling a Humanoid Robot in a Social Environment.” Specifically, the authors compared these two approaches for the goal of controlling robotic gestures. Twenty subjects tried to control the avatar through a real-time first-person view, presented through two cameras positioned in the robot’s eyes. Results were explored in terms of body ownership illusion and usability, drawing on subjective report through questionnaires as well as objective performance measures. Most subjects could elicit robotic gestures with both control methods. Subjects could issue commands more quickly with the eye tracker than the BCI, but reported comparably strong feelings of body ownership with both control methods. This is a novel effort to compare a BCI with eye tracking for navigation. The article is especially engaging because of the first-person immersion and strong effort to explore subjects’ subjective experiences. The authors also note that this work could lead to follow-up studies that combine an SSVEP BCI and an eye tracker. Indeed, hybrid BCIs that utilize these two approaches, in simultaneous and/or sequential mode, could provide additional commands and lead to smoother interaction paradigms.

In the third article, “Multisensory Feedback Can Enhance Embodiment Within an Enriched Virtual Walking Scenario,” Leonardis and co-authors compare two types of feedback: visual only versus visual feedback enhanced with proprioceptive and vestibular feedback. The proprioceptive feedback was provided through artificial tendon stimulation, while the vestibular feedback relied on a moving platform. All types of feedback were designed to reflect the movement of an avatar. Questionnaire results, as well as skin conductance and respiration rate, showed that the novel multisensory feedback enhanced different measures of embodiment. The authors note a major opportunity for improvement: using active instead of passive control, which should further enhance embodiment. Indeed, active BCI controls could lead to new complete systems with numerous mechanisms for engagement.

Overall, these three articles show that the interdisciplinary mix of BCIs, VR and robotics is not only possible, but can enhance users’ feelings of engagement, ownership, embodiment and other measures relative to conventional methods. The articles show how different combinations of these tools, and other external devices, can allow users to control movements and gestures, and experience enhanced embodiment. While these articles provide some answers to the questions posed above, the hybridization of BCIs, VR and robotics remains a relatively nascent research synergy, with many challenges to explore. These articles introduce rich opportunities for future progress, and should inspire promising new work over the next several years.
In keeping with past practice, the articles in the special section are indicated in the Table of Contents with an “S”.

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References


