

Rapid communication

My thoughts through a robot's eyes: An augmented reality-brain-machine interface

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ABSTRACT

A brain-machine interface (BMI) uses neurophysiological signals from the brain to control external devices, such as robot arms or computer cursors. Combining augmented reality with a BMI, we show that the user's brain signals successfully controlled an agent robot and operated devices in the robot's environment. The user's thoughts became reality through the robot's eyes, enabling the augmentation of real environments outside the anatomy of the human body.

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Technologies for direct functional interfaces between brains and artificial devices, the so-called brain-machine (BMI) or brain-computer (BCI) interfaces, have grown impressively in the last decade (Lebedev and Nicolelis, 2006; Birbaumer and Cohen, 2007). One research approach to BMI utilises neurophysiological signals, such as neuronal firing by a single cell. Electrophysiology studies using monkeys or rats have succeeded in multidimensional control of robot arms (Chapin et al., 1999; Moritz et al., 2008), aiming to control revolutionary prostheses that feel and act like the extremities. Another approach utilises neurophysiological signals from the brain, accessed non-invasively, primarily using electroencephalography (EEG), a technique for recording neurophysiological signals using electrodes placed on the scalp. An EEG-based BMI succeeded in achieving two-dimensional cursor control (Wolpaw and McFarland, 2004).

Extensive BMI research has enabled users to control external devices within their own environment; however, the use of brain signals to control devices outside the user's environment remains a new concept for BMI. In situations where humans acquire new visual perspectives, recent neuroscience studies have reported that our body scheme may change (Botvinick and Cohen, 1998; Ehrsson et al., 2004; Lenggenhager et al., 2007), e.g., manipulation of the visual perspective can affect the usual ongoing experience of being located inside our body, and the perceptual illusion of swapping

bodies with another person or an artificial body can occur (Petkova and Ehrsson, 2008). Therefore, one challenge for developing a new BMI is to place the user's visual perspective in another environment directly. This may also raise various points that have to be evaluated further. Another possible direction for new BMI is that of preparing a controllable agent robot that has a visual perspective, and then letting the user see what the robot "sees". Here, we describe a new BMI system that permits the control of devices outside the user's own body environment; we combined augmented reality (AR) with BMI techniques, and showed that brain signals not only controlled movements of an agent robot but also operated a light in the robot's environment, acting through its eyes. The user's thoughts became reality through the robot's eyes, enabling the augmentation of real environments outside the anatomy of the human body.

Ten healthy, non-trained naive subjects (aged 19–39 years; two females and eight males) who had not previously participated in this study were recruited as participants. All of the subjects were neurologically normal and strongly right-handed according to the Edinburgh Inventory. The study was approved by the Institutional Review Board. All subjects provided written informed consent according to institutional guidelines.

The AR-BMI system consists of a personal computer (PC), monitor, lab-made agent robot, USB camera (QCAM-200V, Logicoool, Tokyo, Japan), EEG amplifier (gUSBamp, Guger Technologies OEG, Graz, Austria), and EEG cap (g.EEGcap, Guger Technologies OEG, Graz, Austria) (Fig. 1). When the robot's eyes detect an AR marker (e.g., Fig. 2a), the pre-assigned infrared appliance becomes

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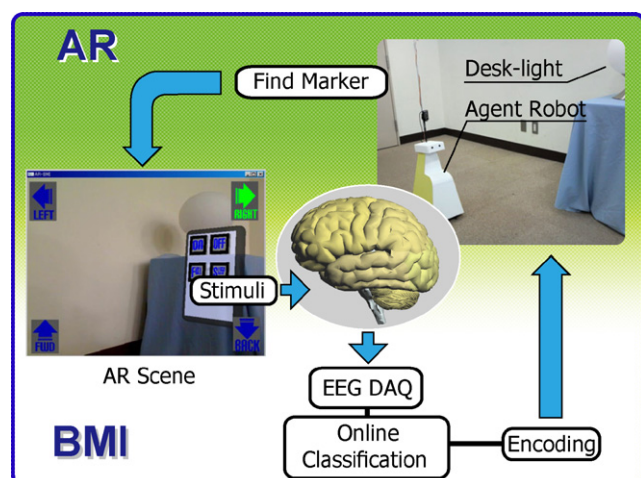


Fig. 1. The augmented reality-brain-machine interface. Subjects were required to watch a computer monitor that displays the scene detected by the USB camera on the agent robot. Four icons to control the robot's movements (forward, backward, right, and left) are shown in the corners of the monitor. When the robot's eyes detect an AR marker, the pre-assigned infrared appliance becomes controllable. A panel with four icons to control the light (turn on, turn off, make brighter, and make dimmer) is also shown on the monitor. Consequently, the subjects can operate the light in the agent robot's environment.

controllable. The position and orientation of the AR marker were calculated from the images detected by the camera, and a control panel for the appliance was created by the AR system and superimposed on the scene detected by the robot's eyes. In order to control our system by using brain signals, we modified a Donchin P300 speller. This uses the P300 paradigm, which presents a selection of icons arranged in a matrix. The subject focuses attention on one of the icons in the matrix as a target, and each row/column or single icon in the matrix is intensified in a random sequence. The target stimuli are presented as rare stimuli (Oddball Paradigm). A P300-related response to the target stimuli is elicited, and then this response can be extracted and classified to determine the target (Farwell and Donchin, 1988). Note that the direction of attention is needed to elicit the P300-related response, and not necessarily the direction of eye-gaze. Recently, our research group modified the Donchin P300 speller (Takano et al., 2009), and applied it through an environmental control system (ECS), enabling a C3/C4-level quadriplegic patient to use the system successfully (28 correct signals/28 trials) without significant training (Komatsu et al., 2008).

The AR-BMI system uses ARToolkit (Kato and Billinghurst, 1999) and OpenGL. The ARToolkit C-language library was used to detect and determine the location of the AR markers, and the OpenGL C-language library was used to draw the 3D control panels. Fig. 2b shows a 3D model of the control panel used to

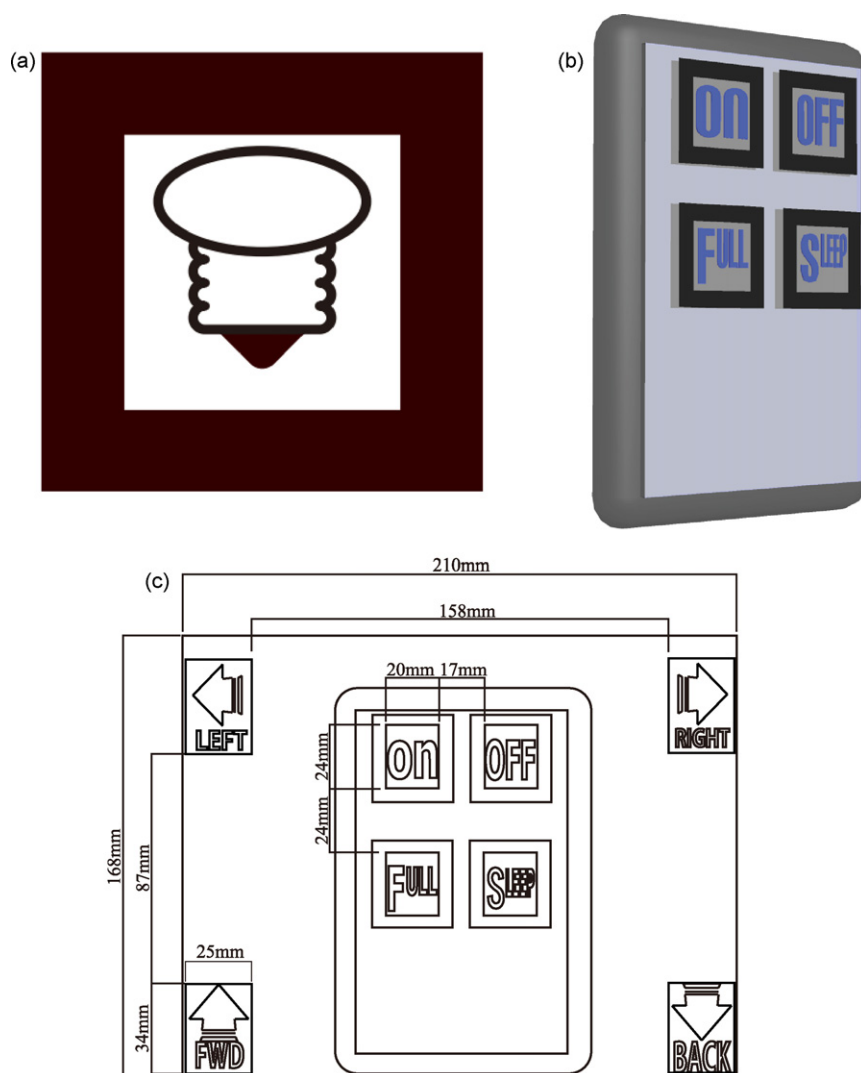


Fig. 2. An AR marker and panels for the AR-BMI. (a) An AR marker for the desk-light control. When the robot's eyes detect the AR marker, it becomes controllable. (b) A 3D model of the control panel used to control the desk light. (c) A drawing of the scene displayed on the PC monitor.

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