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Multiuser Spatial cVEP BCI Direct Brain-robot Control

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Introduction: We present a recently extended by our team spatial code-modulated visual evoked response (cVEP) based BCIs paradigm applied for online control of two humanoid robots NAO in the brain-robot symbiotic configuration utilizing the Internet of Things (IoT) scenario. The presented extension is based on the eight commands BCI paradigm, in which two users simultaneously execute the same movement scenarios. Our previously reported experiments allowed only single user four commands-based BCI [1, 2]. The very encouraging results of two users executing in synchrony the same robot eight-movement-based sequences are a step forward in BCI applications for training and possible artistic performances with healthy as well as handicapped users.

Material, Methods and Results: Brainwave responses in the reported online BCIs, tested with two healthy users in each trial, are captured with two sets of eight active EEG electrodes g.LADYbird connected to two g.USBamp portable amplifiers from g.tec medical instruments GmbH, Austria. The both amplifiers are not synchronized and only digital stimulus series triggers are shared via a g.TRIGbox. The Ethical Committee of the Faculty of Engineering, Information and Systems at the University of Tsukuba, Tsukuba, Japan, has approved the experiments. Direct brain-robot control experiments are conducted with visual steady-state response type of paradigm eliciting cVEP responses [1, 2], classified next with a linear support vector machine (SVM) method. The users are requested to execute only micro eye saccades to gaze directly at one of the eight LEDs flashing 31–bits long m–sequences with eight bits circular shifts applied to differentiate the patterns [1, 2]. The target LEDs are arranged on square frames in front of each user as shown in Figure 1. We apply also 18 single cVEP sequence averaging procedure in online experiments to remove non-cVEP related noise in EEG (each command generated in about 10 s due to slow robot movements). The classified commands are sent to each robot using wireless connection with user datagram protocol (UDP) applied, which realizes the IoT communication scenario. The robots execute pre-programmed commands of walking straight, back, left, right; greeting and saying goodbye; inviting to interact; and stopping without any movement.

Figure 1. *Three screenshots from a video available online [3] documenting the succesful synchronized control of two robots using eight commands' cVEP BCI scenario.*

Discussion and Significance: In the presented novel project of the synchronous and successful direct brain-robot control (with perfect accuracies) by two users simultaneously we could create the new application with possible broad impact on BCI usage training in a master-apprentice scenario (advanced and naïve users). The multiuser robotic control could be also utilized in artistic performances or healthy with handicapped user interactions. The presented novel and successful cVEP-based BCI robotic application is a step forward in development of creative neurotechnology paradigms. Based on experiences with healthy user teams employing the tested direct brain-robot control scenarios we expect that the multiuser BCI application could have a significant potential also for clinical applications to support the user training (rehabilitation or locked-in syndrome cases) or building competitive teams challenging each other. Based on the conducted study we also could observe that the participating users were more encouraged to practice "to move the machines." The robots, as in real life, not always executed the movements perfectly, which required creative feedback from the users. Some situations were also on a border of a comedy of mistaken movements, which further encouraged the users to perform.

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