Augmenting Astronaut's Capabilities through Brain-Machine Interfaces

Michael Broschart[1], Cristina de Negueruela[2], José del R. Millán[2], Carlo Menon[1]
[1]Advanced Concepts Team - European Space Agency/ESTEC
Keplerlaan 1, 2201 AG Noordwijk, The Netherlands
[2]IDIAP Research Institute
Rue du Simplon 4, 1920 Martigny Switzerland
Michael.Broschart@esa.int, Carlo.Menon@esa.int, cnegueruela@gmail.com, jose.millan@idiap.ch

Abstract

Brain-Machine Interfaces (BMIs) transform the brain activity of a human operator into executable commands that can be sent to a machine, usually a computer or robot, to perform intended tasks. In addition to current biomedical applications, available technology could also make feasible augmenting devices for space applications that could be promising means to improve astronauts' efficiency and capabilities. The implementation of artificial intelligence algorithms into the software architecture of present BMIs will be of crucial importance to guarantee a proper functionality of the device in the highly dynamic and unpredictable space environment.

1 Introduction

There is no doubt that space is a demanding environment, and space missions are among the most exciting endeavors undertaken by humankind. As it has been demonstrated during the almost 50 years of space age, a key factor for a successful space mission is a high degree of on-board autonomy, in particular when the spacecraft is traveling beyond Earth's orbit. Communication delays in the order of hours between the spacecraft and its ground segment prevent a real-time handling of information which in turn poses a challenge to the process of decision-making and crisis handling.

In this context, in the highly dynamic and unpredictable space environment, long-term robustness and survivability can only be ensured by a smart and adaptive behavior of the spacecraft and its subsystems towards unexpected events and perturbations [Ayre, 2004]. This inevitably requires an increased degree of on-board autonomy and embedded intelligence, and smart systems that take advantage of artificial intelligence (AI). For human missions, there are added requirements, and an efficient interaction between astronauts and space technology is a second key factor. In this paper we focus on human-machine communication, and we present the novel research avenue of Brain-Machine Interfaces (BMI) for space applications.

2 Brain-Machine Interfaces

A BMI monitors and acquires the brain activity of a user, analyses it to determine the intent of the subject on the basis of the frequency and the cortical areas activated, and finally transmits these signals as executable commands to a computer or robotic device [Menon *et al.*, 2006].

Among the different methods that are currently studied to monitor brain activity, such as Magnetoencephalography (MEG), functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET), Near-Infrared Systems (NIRS) and Electroencephalography (EEG), only the latter is currently promising for space applications, mainly due to its portability, low power consumption, and fine temporal resolution [Carpi and De Rossi,, 2006; Menon *et al.*, 2006; Tonet *et al.*, 2006]. Moreover, the EEG method is non-invasive; the user's body is not penetrated neither by incision nor injection or administration of pharmaceuticals.

Typical EEG systems measure bioelectrical brain signals, which are modulated by mental activity, e.g. the imagination of a hand or finger movement, directly from the user's scalp and transform them into output signals that can be used for the generation of hardware control action.

In general, EEG signals are characterized by a poor signal-to-noise ratio [Millán *et al.*, 2006]. Therefore, special importance is attributed to advanced filtering methods and sophisticated noise cancellation techniques for the reliable extraction of the relevant features related to mental activity. A well-trained feature classifier is crucial for the correct recognition of the user's intentions to finally generate the intended action.

Nowadays there are numerous research groups working on BMIs, and some prototypes have already been successfully demonstrated. The ultimate application in which the efforts are put into is to give physically impaired people the possibility to move and communicate with their environments by the force of their thoughts [Millán *et al.*, 2006; Tonet *et al.*, 2006]. Recently, it has been demonstrated that human subjects can drive a robot, only "by thinking", through a structured house-like environment as the result of shared human-machine control [Millán *et al.*, 2004a,b].

3 BMIs for space applications

As suggested by experiments performed under laboratory conditions on Earth, brain-controlled robotic devices [Millán *et al.*, 2004a,b] and surface rovers, as well as semi-automatic manipulators are seen as the most relevant fields of application [Tonet *et al.*, 2006]. These could bring numerous benefits for astronauts, such as teleoperations to reduce the hazards of extra-vehicular activities (EVA) on the one hand and to optimize the efficiency of astronaut activity on the other. Commands could be sent with high accuracy and in real-time, enabling astronauts to perform various tasks simultaneously using only one single BMI. Robotic aids could be very useful to assist astronauts that are physically weakened after long-duration stays in space [Menon *et al.*, 2006]. However, there is a need to incorporate shared autonomy principles into the BMI [Millán *et al.*, 2004b], in a sense that an intelligent controller is relieving the human from redundant low level tasks; but, in any case, the astronaut would keep his cognitive superiority and adaptability of acting in unforeseen situations.

Nevertheless, it must be taken into consideration that microgravity and other stressors related to spaceflight most probably will have influence on the functionality of the BMI. In addition, effects of cosmic particle radiation that interact with the visual system, a phenomenon known as "light flash", might interfere with the BMI [Tonet *et al.*, 2006]. For these reasons, we can not presume *a priori* that a BMI functioning properly on Earth will behave in the same manner in space. In the worst case scenario, it could stop working or would require a new adaptation of the algorithm to account for the psycho-physiological modifications of the human Central Nervous System [Tonet *et al.*, 2006].

A possible avenue to follow is the implementation of routines and control architectures based on AI algorithms. In particular artificial neural networks (ANN) and Fuzzy logic are an efficient way to anticipatory and proactive software behavior, mimicking the process of biological learning [Ayre and Lan, 2006], to tune the classifiers accordingly. ANNs are well suited for on-line adaptation of the parameters of conventional proportional-integral-derivative (PID) controllers for a quick and optimal control of external perturbations, even of strong non-linearity.

The authors are currently performing technology tests to check the feasibility and efficiency of non-invasive BMIs in microgravity (space) and hypergravity environment (e.g. during launch) using commercially available EEG systems.

4 Conclusions

In space, it is essential that not only any working structure, but also the astronauts fully accomplish their assigned tasks for a successful mission. Astronauts are specially trained and on a long-term basis, we expect them being able to use BMIs as augmenting interfaces, i.e. in addition to conventional interfaces (keyboards, joysticks, etc.) to increase their operative capabilities.

Prototypes of BMIs as communication devices, care robotics and assistive robotic devices in the field of rehabilitations, or in domotics and environmental control, are under applicative investigation; technology is ready [Tonet *et al.*, 2006], although performance is still lacking with regard to throughput and efficiency. But expertise and global research in that field is rapidly advancing, and more satisfying solutions are already predictable in a near future.

Regarding the potential of BMIs for space applications, we foresee that AI, implemented into the control paradigms of BMIs, will be an essential milestone. ANNs are extremely adaptive and failure-tolerant, enabling real-time adjustments to a BMI system to allow its proper operation in the challenging space environment. This research might lead to new levels of on-board automation, autonomy, and efficient, mind-controlled human-machine interaction.

5 References

[Ayre, 2004] M. Ayre. Biomimetics Applied to Space Exploration. In Proc. of 2nd Int. Conf. Design&Nature, Rhodes, Greece, June 2004.

[Ayre and Lan, 2006] M. Ayre and N. Lan. Biomimetic Engineering for Space Applications. ESA SP-127, 2006.

[Carpi and De Rossi,, 2006] F. Carpi and D. De Rossi. Non Invasive Brain-Machine Interfaces. ESA Ariadna Study 05/6402, ESA Contract 19706/06/NL/HE, 2006.

[Menon *et al.*, 2006] C. Menon, C. de Negueruela, J. del R.Millán, O. Tonet, F. Carpi, M. Broschart, P.W. Ferrez, A. Buttfield, P. Dario, L. Citi, C. Laschi, M. Tombini, F. Sepulveda, R. Poli, R. Palaniappan, F. Tecchio, P.M. Rossini, D. de Rossi. Prospective on Brain Machine Interfaces for Space System Control. 57th IAC Conference, Valencia, Spain, 2006.

[Millán *et al.*, 2004a] J. del R.Millán, F. Renkens, J. Mouriño, W. Gerstner. Brain-Actuated Interaction. Artif. Intell. 159, pp. 241–259, 2004.

[Millán *et al.*, 2004b] J. del R.Millán, F. Renkens, J. Mouriño, W. Gerstner. Non-Invasive Brain-Actuated Control of a Mobile Robot by Human EEG. IEEE Trans. Biomed. Eng. 51, pp. 1026–1033, 2004.

[Millán *et al.*, 2006] J. del R. Millán, P. Ferrez, A. Buttfield. Non Invasive Brain-Machine Interfaces. ESA Ariadna Study 05/6402, ESA Contract 19708/06/NL/HE, 2006.

[Tonet *et al.*, 2006] O. Tonet, F. Tecchio, F. Sepulveda, L. Citi, M. Tombini, M. Marinelli, F. Focacci, C. Laschi, P. Dario, P.M. Rossini. Critical Review and Future Perspectives of Non-Invasive Brain-Machine Interfaces. ESA Ariadna Study 05/6402, ESA Contract 19707/06/NL/HE, 2006.