Robot Control on the basis of Bio-electrical signals

Jorge Ierache[1,2,3], Martin Dittler[3], Gustavo Pereira[3], Ramón García Martínez[1,2].

Computer Science PhD Program. Computer Sc. School. La Plata National University[1]
Intelligent Systems Laboratory. Engineering School. University of Buenos Aires[2]
Instituto de Sistemas Inteligentes y Enseñanza Experimental de la Robótica FICCTE[3]
Universidad de Morón, Cabildo 134, (B1708JPD) Morón, Buenos Aires, Argentina Cabildo 54
11 5627 200 int 189
jierache@unimoron.edu.ar

Abstract. This article shows the experiences carried out in the context of human/robot communication, on the basis of brain bio-electrical signals, with the application of the available technologies and interfaces which have facilitated the reading of the user's brain bio-electrical signals and their association to explicit commands that have allowed the control of biped and mobile robots through the adaptation of communication devices. Our work presents an engineering solution, with the application of technological bases, the development of a high- and low-level communication framework, the description of experiments and the discussion of the results achieved in field tests.

Key words: Robots, Brain Machine Interface, Bio-Electrical Signal, Human Machine Interfaces.

1. Introduction

The application of bio-electrical signals for the control of systems, robots, applications, games and devices in general presents an original approach as it opens up new possibilities for the interaction of human beings and computers in a new dimension, where the electrical biopotentials registered in the user are specifically exploited; these biopotentials include the EMG (electromyogram), the EEG (electroencephalogram) and the EOG (electro-oculogram), which are bio-electrical signals generated by activity patterns in the user's muscles, brain and eyes. The idea of moving robots or facilitating the application of devices for the physically disabled people by controlling them only through the brain activity, with no use of manual controls, has fascinated researchers.

In this regard, several works have been presented; the first ones resorted to the implantation of intracranial electrodes in the motor cortex of primates [1], [2]. Non-invasive works for humans resorted to EEG signals, applied to mental command exercises, such as moving the computer cursor[3], [4] based on the use of Brain-

Machine Interface (BMI). Millan et. al [5] show how two people are able to move a robot by using a simple electroencephalogram on the basis of recognizing three mental states, which are associated to robot commands. The works presented by Saulnier et al. [6] focused on controlling robot speed and further inferring the user's stress level, thus influencing on the social behavior of domestic robots, in this case of a robotic vacuum cleaner. Millan et al´s seminal work [5] uses the EEG as a unique bio-electrical signal, on the basis of the work of two people to support robot navigation; in contrast to this, our work presents the preliminary result by applying a low-cost BMI, used in secondary works like that by Saulnier et al[6] that includes bio-electrical signals corresponding to the electroencephalogram, the electro-oculogram and the electromyogram. Unlike Saulnier et al´s work, in which speed control is implemented on the basis of the electromyogram and the user's stress level is inferred on the basis of the electroencephalogram, our work focuses on the execution of a navigation pattern task by a robot, by comparing the manual control and brain control operating times during the beginning of a user's learning curve, with results that show that the brain control requires in general terms twice as long as the manual control for the execution of the same navigation pattern. However, in the context described our work introduces an improvement in the brain control times slightly exceeding the manual control in the execution tests of the same navigation pattern, which we call brain control with auto-focus. In our research work the V1 Robosapiens Biped robot from the Woo Wee Robotics family [8] was used for the preliminary tests and as main robot a simple mobile one on the basis of an NXT Lego was assembled [9].
In the second part of this work it is presented the problem to be solved in the context of the use of a BMI for the control of robot behaviors, the difficulty in the process of selection of robot behaviors. In the third part it is proposed the solution, with a description of the BMI used, the brain control of each robot behavior, and the features of the integration framework. Finally in the fourth part the comparative results obtained from the tests carried out with manual control, brain control and brain control with auto-focus are discussed, being the latter presented as a solution for the selection of robot behavior through brain-actuated control.

2 Problem

Our initial objective was to explore an engineering solution that allows us to achieve a primary integration of a BMI and a robot so as to be used by a user who does not need to have previous experience in meditation techniques or specific training in mental concentration.
For the brain control of a robot, two commands were set out: one enabling the control of behavior **selection** and another one making it possible the **execution** of robot behavior on the basis of its own controllers (for example moving forward in the case of the biped robot or turn right in the case of the mobile robot), with no major difficulties when associating the **execution** to a muscular bio-electrical signal stimulus.

Nevertheless, the **selection** of a behavior (in our context those behaviors corresponding to the menu of the family of robot behavior) through brain control, on the basis of bio-electrical signals coming from the electroencephalogram, **was not practical for the user**, due to the difficulty in controlling the menu of behavior selection **in a stable way** .

3. Solution description

It is established an experimental architecture having two communication models; the first model, and main study subject, is called high-level communication model: "user-computer"; this model was implemented with an low-cost OCZ NIA BMI[10], which is used in an experimental way in videogames and makes it possible the association of brain signal patterns with the computer keyboard and computer mouse. Taking this into account, it was determined a simple profile for robot operation that associates and characterizes in the first place the control for **the execution** of the mental command on the basis of the detection of muscle signals, in our case through a slight eyelid movement, and in the second place **the selection** of the robot high-level commands, working in this case on the basis of Alpha brainwaves. This type of bioelectrical signals did not guarantee the user an adequate control in the displacements through the menu of command selection of the robot's control framework. For this reason it was implemented the option of auto-focus application for brain control mode in the framework in order to improve the user's management in the selection process. The second communication model, called low-level communication model: "computer-robot", was implemented in the case of the V1 Robosapiens through an IR Tower [11], and in the case of the NXT mobile robot its Bluetooth communication capabilities were exploited. The communication with robots done via IR was based on the results obtained in the capture and reproduction of commands controlled from a computer [12].

3.1 Brain-Machine Interface

The Neural Impulse Actuator (NIA) was used as a brain-machine interface / BMI [10]. It is composed of a driver control unit (figure 1) and a headband with three diamond-shaped sensors, which is put on the user's forehead (figure 2), manufactured using carbon fiber nanotechnology. The driver control unit is connected to the computer and fed via a USB 2.0; the software that comes with the NIA allows the calibration, training and definition of the control profiles that make up the applications.

The preparation of the profile to control the robot makes it necessary to think about the intuition of the robot behavior that is intended to be controlled. BMI capabilities are different from those of a keyboard, so control strategies are to be adjusted consequently to take advantage of the more limited reaction times and the higher level of immersion in robot behavior.

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Fig. 1. BMI-NIA

Fig. 2. Headband – NIA

The BMI-NIA has an application having a control and configuration panel to allow auto-calibration of the recorded biosignals (Fig.3) through its components: the electro-oculogram that detects eye glancing (eye movement activity), the electroencephalogram that records Alpha brain waves (9-13 Hz, present in the following situations: wakefulness, normal alertness and consciousness) and the beta waves (14-30 Hz, present in the situation of being relaxed, calm, lucid, or not thinking), and finally through the electromyogram that detects muscle amplitude. Moreover, the application has some tools for the creation and editing of profiles that allow the association of biosignals with keyboard commands.

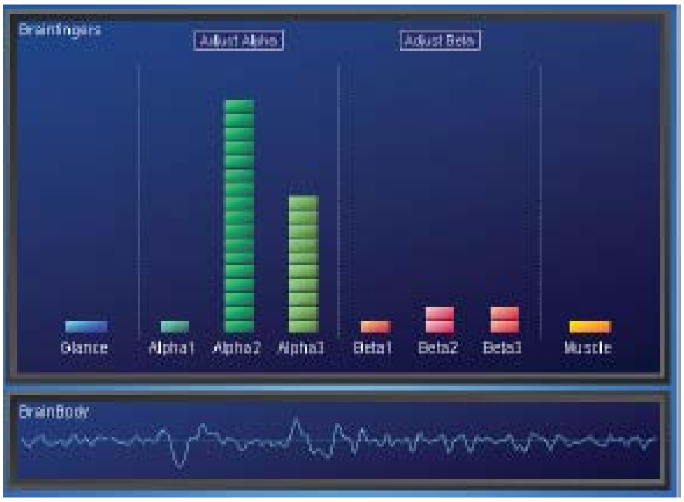


Fig. 3. Biosignal panel

For the creation of profiles in the BMI-NIA, switch events are firstly considered; they are thought to select actions that require precise timing for these switch events, like for example jumping in an action game, turning right in the case of a mobile robot or taking a step to the right in the case of a biped robot. The switch events can further be assigned a single data transfer, single mouse click or keystroke or a hold function. In the latter case, the action bound to the key will continue as long as the switch event remains active. The BMI-NIA allows us to bind the profile up to three different switch events. The BMI-NIA considers as a second step for the creation of a profile, the creation of up to four joysticks (horizontal, vertical, parallel). Each vertical joystick allows the definition of up to four different zones, for each zone up to three switch events may be stated; moreover, several modalities may be assigned to each zone (on/off, hold the key for a certain time, a single click, delay the activation for a defined time, repeat at a defined interval, repeat and hold, etc.) Every biosignal can be used in one or more parallel joysticks that use the same input biosignal; the result is equal to pressing two or three keys on the keyboard simultaneously. Four zones, two left ones and two right ones, can also be assigned to the horizontal joystick; it is applied with the “glance” biosignal coming from the electro-oculogram. This signal follows the lateral eye movements and could be used so that the robot may turn right or left. The same as in the case of the vertical joystick, up to three switch events and modes are defined for each zone. Each joystick can be separately adjusted with respect to the level, amplification and smoothing of biosignals.

3.2 Brain-actuated control of robot’s behavior

The communication of robot behaviors is implemented in two communication models (Fig.4), a high-level one between the BMI-NIA and the framework, and a low-level one between the latter, by means of the communication transmission device, and the robot.

The high level communication model, developed for the integration of the mental commands with the behaviors associated to the mobility of the Robosapiens V1 and the NXT respectively, functions between the BMI-NIA and the framework, where the selection and execution of motion behaviors for the biped robot and the mobile robot take place, by means of the mental commands captured by the BMI-NIA according to the profile for the robot control. The profile associates and characterizes firstly the control for the execution of mental commands on the basis of a switch event bound, in our case, to the “spacebar” key in single mode, being its activation controlled by muscle biosignal, with a gentle eyelid movement.

Secondly, for the selection of the robot’s high-level commands it was defined in the profile a vertical joystick (1°), which is activated on the basis of the Alpha 1 waves, being the event bound to the “F” key, in zone ZI. To improve the user’s control in the displacement by means of the selection menu, the framework enables the activation of auto-focus. The auto focus is BMI-independent; it is used in our framework to make a sequence of the commands according to the test pattern. Although the auto focus functionality assists the user, it does not replace the event of the command mental selection; it only makes a controlled sequence, unlike the brain control mode (without the use of the auto focus) that does not control command sequencing, thus requiring a bigger effort on the part of the user.

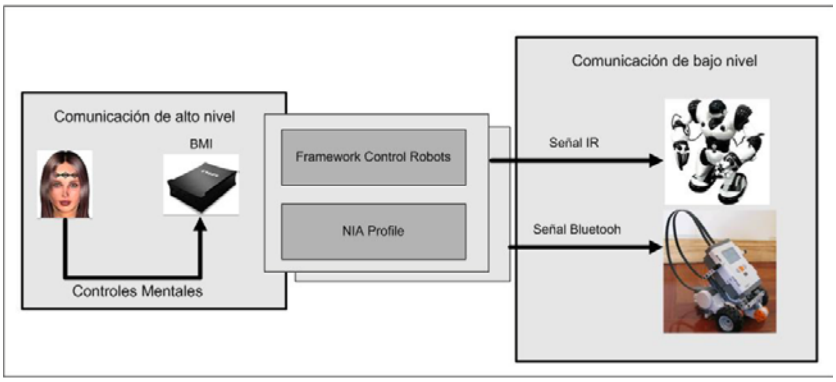
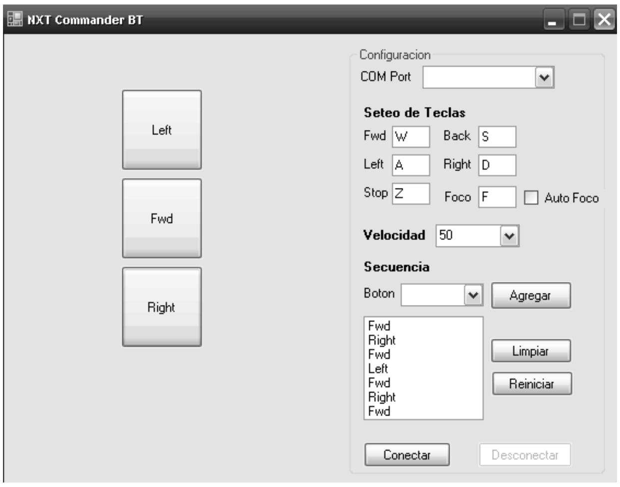


Fig. 4. Robot- BMI-NIA Integration

The framework configuration (Fig.5) for the fulfillment of the tests in the ´brain control with auto-focus´ mode adopted the following command path: left-stop, forward-stop, right -stop. The execution of the ´forward´ command was set to 2 seconds and the turns to 50 seconds. For the brain control (without auto-focus) tests said function was deactivated and it was used the same framework as in the manual control, with the same time parameters for the execution of forward and turn motions.



Fwd W
Back S
Left A
Right D
Stop Z
Foco F
☐ Auto Foco
Velocidad 50

Fwd
Right
Fwd
Left
Fwd
Right
Fwd

Fig. 5. Mobile Robot Framework

4. Result Discussion

Even though all the features of the BMI-NIA have not been mastered so far, we can comment that whenever used it is to be calibrated; although it was found out that calibration has not always been necessary, it is better to calibrate it before each test session period. On several occasions, the desired results were not achieved, particularly in the first attempts due partly to the equipment sensitivity to electromagnetic fields, and it was also found out that the user could exert some influence when touching the BMI-NIA. Throughout the initial trainings, the users became tired and needed some rest after approximately 30 minutes. At the beginning, the user makes muscular motion in an exaggerated way, but with practice and the improvements on profile calibration, the muscle movements are minimized. The tests performed with the biped robot were oriented to the free execution of mental commands and were the basis for the preparation of more complex tests with the mobile robot. One of the functional tests of free execution of the biped robot was video-documented [13]. The mobile robot tests were carried out in an experimentation area (2.00 meters x 1.50 meters) on which four check-points (Cp), distributed according to a pattern (Fig.6) were marked. The first test case was that of the manual control (MC) of the robot controlled by the user; for this case three training sessions and three test sessions were performed. The second test case was that of the brain control (BC); nine previous training sessions and three test sessions were carried out. The third test case was performed in order to check the work proposal, regarding the application of brain control with auto-focus (BC-AF) in the command to be executed, according to the navigation pattern; for this mode six training sessions and three test sessions were carried out.

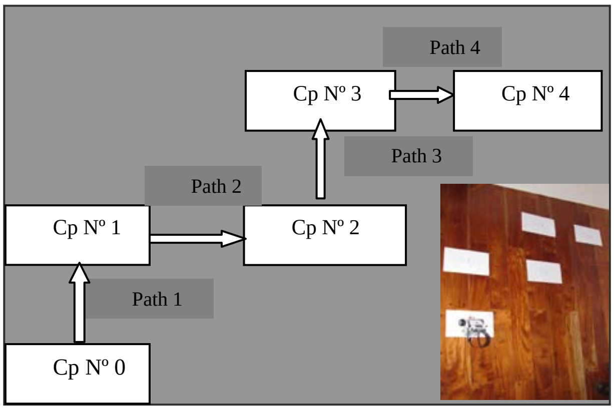


Fig. 6. Mobile Experimentation Pattern

For each test session, the partial times of each path defined between each check-point (Cp) –as detailed in table 1 “Mobile robot experimentation outcomes”- were obtained. The preliminary outcomes indicated that the combination of brain control with auto-focus (BC-AF) was quicker that the manual control solution; however, in general terms the Brain control (BC) solution was slower than the manual control (MC) solution. Table 1 shows the comparative average results obtained in the three test sessions corresponding to each control case (manual, brain, brain with auto-focus, respectively): (a) the time per path between each check point, (b) the total time to perform the pattern, (c) the time difference between manual control and brain control, (d) the time difference between manual control and brain control with auto-focus, (e) final percentages between manual control and brain control, final percentages between manual control and brain control with auto-focus. The second section of Table 1 shows the cumulative times between paths and the total time. Finally, to summarize we could state that the brain control with auto-focus was 11.32 % better than the manual control, though the manual control was 111 % better than the brain control (without auto-focus).

Table 1. Mobile robot experimentation outcomes

Type of Control	**Manual**	**Brain**	**Brain Control**
Average time between Path	**Control (MC)**	**Control (BC)**	**with Auto focus (AF)**
Path 1	**00:02,85**	**00:02,19**	**00:01,84**
Path 2	**00:04,92**	**00:08,09**	**00:04,43**
Path 3	**00:04,91**	**00:13,60**	**00:04,50**
Path 4	**00:04,44**	**00:11,47**	**00:04,43**
Total Time	**00:17,13**	**00:36,16**	**00:15,19**
Delta Time MC-BC		**19,03**	
Delta Time MC-BC + AF			**1,94**
% MC-BC		**111%**	
% MC-BC+AF			**11,32%**
CumulativeTime	**Manual**	**BC**	**BC-AF**
Path 1	**00:02,85**	**00:02,19**	**00:01,84**
Path 2	**00:07,78**	**00:11,09**	**00:06,27**
Path 3	**00:12,69**	**00:24,69**	**00:10,76**
Path 4	**00:17,13**	**00:36,16**	**00:15,19**
Total Time	**00:17,13**	**00:36,16**	**00:15,19**

Fig. 7 shows the comparative distribution of average times of the test sessions for each path: with manual control, brain control and brain control with auto-focus, respectively. Finally Fig.8 shows the total time for each path, for each test according to the control type (manual control, brain control and brain control with auto-focus, respectively). To complete the navigation pattern, the second brain control test (test 2 BC) was the one which took longer (45.47 seconds) and the third test of brain control with auto-focus (test 3 BC-AF) was the one that took less time (13.93 seconds) to complete the same navigation pattern. Some parts of the mentioned tests were video-documented: brain control [14], brain control with auto-focus [15]

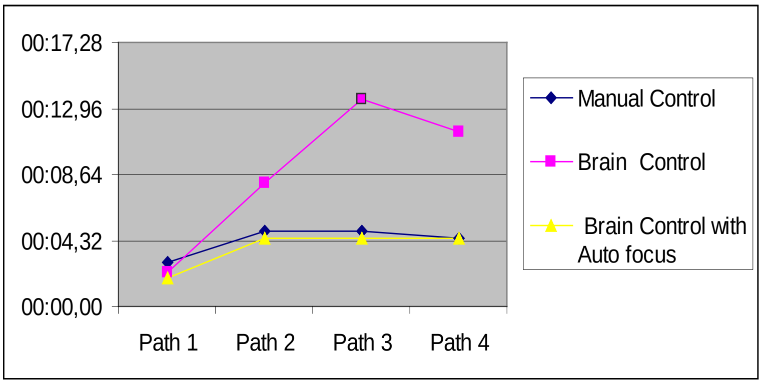


Fig. 7. Average time between paths

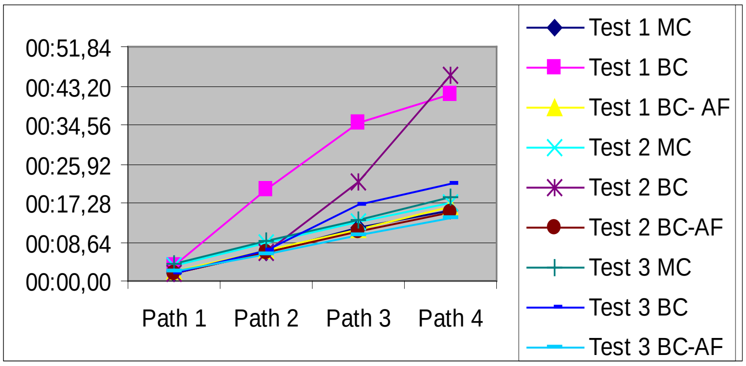


Fig. 8. Total time for each test

5. Conclusions

Due to the experience and the outcomes obtained in the preliminary tests of human-robot integration through brain-actuated control, we could enter a new dimension of communication. As a result of the tests performed in a real environment with physical limitations, for example the slight floor undulation, the final outcome was that the brain control with auto-focus mode slightly exceeded the manual control. Although the manual control exceeded the brain control in terms of time for the execution of the navigation pattern, this is to be considered in a preliminary framework within the beginning of the user's learning curve with BMI memory. In conclusion, this experience allows us to appreciate the wide potential of applications, especially those oriented to physically disabled people, as well as human interaction in a direct way with context-centered applications, and the future potential of human-robot collaboration among other possible fields. Our future research lines will focus on the development of an integrating framework for robots, the interaction with the robot perception through its environment sensorization, the robot's learning process through the sharing and collaboration of actuators and the study of new BMIs, as well as the continuity of the users´ practice and experimentation, adapting their memory to the context of BMI applications.

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13 Video Bípedo: http://www.youtube.com/watch?v=-04JjfMcdfU

14.Video Brain control: http://www.youtube.com/watch?v=LhKV50jNgcY

15.Video Brain control con auto foco: http://www.youtube.com/watch?v=hD9CvQlNxho