Probabilistic Scan Mode of a Robot Manipulator Workspace Using EEG Signals. Part I

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Abstract. In this paper a probabilistic-based workspace scan mode of a manipulator robot is presented. The scan mode is governed by a Brain Computer Interface (BCI) based on Event Related Potentials (Synchronization and Desynchronization events). The user is capable to select a specific position at the robot’s workspace, which should be reached by the manipulator. The robot workspace is divided into cells. Each cell has a probability value associated with it. Once the robot reaches a cell, its probability value is updated. The mode the scan is made is determined by the probability of all cells at the workspace. Finally, the manipulator is teleoperated via TCP/IP.

1. Introduction

Brain Computer Interfaces have got a great impulse during the last few years. The main reasons for this growing are the availability of powerful low-cost computers, advances in Neurosciences and the great number of people devoted to provide better life conditions to those with disabilities. These interfaces are very important as an augmentative communication and as a control channel to people with disorders like amyotrophic lateral sclerosis (ALS), brain stroke, cerebral palsy, and spinal cord injury ([1], [2]).

The main point of a BCI is that the operator is capable to generate commands using his/her EEG (electroencephalographic) signals in order to accomplish some specific actions ([2], [3], [4], [5]). Thus, an operator using a BCI can control, for example, a manipulator, a mobile robot or a wheelchair (amongst other devices) without using any muscle. The EEG frequency bands have enough information to build an alphabet of commands in order to control/command some kind of electronic device ([6], [16]). In this paper a BCI, which is controlled through alpha waves from the human brain, is used ([6]). Although the EEG signal acquisition/conditioning, which is part of this BCI, was developed in other work of the authors, one of the objectives of this paper is to illustrate its versatility, mainly in terms of the simple algorithms used. The first paragraph after a heading is not indented (Bodytext style).

Event related potentials (ERP) in alpha frequency band are used here. Such potentials are ERD (Event Related Desynchronization) and ERS (Event Related Synchronization), well described in the following sections. This BCI has a Finite State Machine (FSM) which was tested in a group of 25 people. Experiment results as well as a detailed description of this BCI can be found in [7].
The main objective of the application here addressed is to allow the user to command a manipulator, based on a probabilistic scan of the robot’s workspace. Figure 1 shows the basic structure of a BCI.

One can see the different modules of a BCI. The EEG signal acquisition module is responsible for the filtering and amplification of the EEG signal (signal conditioning). The data acquisition module is represented, basically, by an A/D converter. In pre-processing phase filters and algorithms are used to remove artifacts ([8]).

![Figure 1. Basic structure of a BCI](image)

The feature extraction module gets the information and identifies the EEG signal characteristics that will be used by the next module (classification) to make a decision. The next step is the control signals generation and after that these control actions are sent to a device, in this case a manipulator. More information can be obtained in ([8], [9], [10]).

This paper was divided into two parts. Part I is organized as follows: the manipulator used during the experimental phase (which can emulate a small arm placed on a mobile robot or on a wheelchair) is described in Section 2. The application software developed, including the graphical interface and the scan mode, is presented in Section 2 and 3 as well as its characteristics. The complete system is shown in Section 4. In the Part II of this work, the mathematical derivation of the probabilistic scan mode is shown also with the experimental results for several situations. These experimentations show the probabilistic behavior of the workspace among with the evolution of cells’ probabilities.

## 2. Dynamic model of bosch sr-800 manipulator

In the absence of disturbances and without considering gravity effects, the dynamics of rigid manipulators with $n$ joints, can be modeled in joint space by,

$$M(q)\ddot{q} + C(q, \dot{q})\dot{q} + f(q) = \tau$$  \hspace{1cm} (1)
where \( q \) is a \( nx1 \)-vector of joints angular positions, \( \tau \) is a \( nx1 \)-vector of applied moments, \( M(q) \) is the \( n \times n \) inertia matrix positive defined, \( C(q, \dot{q}) \) is the \( n \times n \) matrix of centrifuges moments and Coriolis effects, and \( f(\dot{q}) \) is a \( n \times 1 \)-vector of friction moments.

The manipulator's model has a structure presented by (1). A SCARA manipulator SR-800 Bosch (figure 2) was used during the experimental phase of this work. Equations that model the gears of each joint and its associated load can be extended to the case of a manipulator with two degrees of freedom, using equation (1). Thus, equation (1) can be rewritten as it is shown in equation (2).

The manipulator's identified constants and additional information can be found in [11].

\[
\begin{bmatrix}
J_{m1} & 0 & \ddot{q}_1 \\
0 & J_{m2} & \ddot{q}_2 \\
\end{bmatrix} + \begin{bmatrix}
\alpha_1 & 0 & \dot{q}_1 \\
0 & \alpha_2 & \dot{q}_2 \\
\end{bmatrix} = \begin{bmatrix}
\frac{1}{\gamma_1 R_1} & 0 & v_1 \\
0 & \frac{1}{\gamma_2 R_2} & v_2 \\
\end{bmatrix}
\]  

(2)

Figure 2. Manipulator Bosch SR-800.

3. Dynamic model of bosch sr-800 manipulator

A graphical interface (figure 3) was developed in order to make an easy operator/manipulator interaction. Basically, its function is to generate commands to the manipulator based on the EEG signals received from the operator. Moreover, the interface also provides a visual feedback to the operator using the signals received from the remote client (PC). Beyond the simplicity of operation and of being friendly to the operator, another important characteristic of this interface is to be written in C/C++ and of using the graphical library wxWidgets, allowing its portability in an easy way. A great advantage of this graphical package is to be multiplatform, compiling codes in C/C++ to different operating systems (Linux/Unix, Mac OS and Windows) and using the native Graphical User Interface (GUI) of each platform.

The information available in this interface are: the coordinates sent to the manipulator; the received positions from encoders; information incoming from the data acquisition board ADQ12 (A/D converter); ERS threshold to cause a change on the scan mode and also the system status, informing the operator if the system is ready (or not) to receive another command and finally, all the information related to the probability accesses values to each position of the manipulator on the workspace used.
This graphical interface is divided by the following modules: EEG signals processing (the signals acquired by ADQ12), bidirectional communication (sends commands to manipulator and receives positions from the encoders), direct/ inverse kinematics generator of Bosch manipulator and a module to control the scan mode of the cells in the manipulator's workspace. The mentioned modules are presented as follows:

### 3.1. Signals Processing
The EEG signals acquired by the BCI already filtered and amplified are digitalized by the acquisition board ADQ12 and after that are processed by the application. The frequency band used is from 8 Hz to 13 Hz (alpha band). The EEG signals explored are event related potentials, called Event Related Desynchronization (ERD) and Event Related Synchronization (ERS). These signals belong to a group of EEG potentials ([2]).

These signals are energy changes on the brain rhythms in a specific frequency band. The ERD represents a decreasing of this energy while ERS represents an energy increasing. These potentials are present in the alpha band of the occipital region (region related to the processing of visual information). The ERD is related to concentration or existence of visual stimulus, for example, when the operator has the eyes opened. When the eyes are closed, the human operator has his visual area relaxed with few, or absence, of visual stimulus, characterizing an ERS. At this module, the operator's intention in selecting a specific action, for example a change on the scan mode, is recognized when the ERS level reaches over the set ERD threshold (5 to 10 times the normal ERD level, see figure 4).

### 3.2. Bidirectional Communication
In this work a communication between the BCI (application) and a remote manipulator through a TCP/IP channel was also implemented. The communication is based on socket TCP/IP ([12]), allowing, for example, teleoperation of the manipulator via Internet. A server TCP/IP runs on the local PC, with Linux as operating system, while a remote PC executes a client TCP/IP.
Figure 4. Energy increasing during an ERS.

The remote PC runs QNX Real Time Operating System and controls the manipulator. Once initialized, the client calls the server and the connection starts. After that, the teleoperation is turned on, allowing the commands received via TCP/IP to be executed locally. The remote PC is now ready to receive new incoming pose references from the human operator and also is ready to send the encoder's information back to the server (local PC). Thus, a feedback is established, providing visual information to the operator about what is happening at the manipulator's workspace while it executes the tasks.

3.3. Direct/Inverse Kinematics Generator
To send a new reference point selected by the operator to the manipulator it is necessary to calculate the inverse kinematics: for a given tool's position, angular positions of the joints are calculated which provide the desired configuration. Then, this coordinates are sent to the client PC to guide and control the manipulator until reaching the desired position. In a similar way, it is also necessary to calculate the direct kinematics using the encoder's information incoming from the client PC: for a given joints configuration, tool pose (position and orientation) is generated. With this information, it is possible to build a good representation of the manipulator's workspace to the operator (visual feedback).

3.4. Scan Mode Control
The main contribution of this work is the scan mode algorithm proposed. It is based on the probabilistic information of each cell at the workspace. When the application starts, the workspace of the manipulator is shown to the operator. The workspace is divided into cells. Each cell contains three values: its position \((x, y)\) at the robot's workspace plane and a probability value. This value indicates the accessibility of that element. That is, if a cell has a close to zero probability, then, it has low probability to be accessed. Once a particular cell is accessed, its probability is updated based on Bayes’ rule. The next section shows step by step the way the scan algorithm works.

3.5. Scan Algorithm
1. The workspace’s resolution is set to 72 cells (according to [13]) and can be easily changed, decreasing or increasing this number.
2. Each cell has its own initial probability. This value can be previously determined by some heuristic method (for example: if the BCI operator is right-handed, then cells to the right of the workspace will have higher accessing probability than the ones to the left). However, it is also possible to set all cells to a probability near zero, in order to increase or decrease them depending on the times they are accessed by the user. In this work, the first case was adopted.
3. Let \( a \) and \( b \) be the higher and lower probabilities cells respectively. Then, the workspace is divided into three zones according to these values. Table 1 shows how division is made. Let \( P(C_i \mid G) \) be the probability of cell \( C_i \) given a group \( G \) to which it belongs.

4. Every zone at the workspace is divided in three sub-zones under the same philosophy presented before. Each one of these sub-zones contains a set of probabilistic weighted cells.

5. The scan mode proceeds as follows:
   I. First, the zone with the highest probability value at the workspace is highlighted. If that zone is not selected by the operator, the second highest probabilistic zone is highlighted. If it is not selected, the highlight passes to the third and last zone. The scan keeps this routine until a zone is selected.
   II. When a zone is selected, the highlight shows first the sub-zone with the highest probability inside the zone previously selected. The scan, in this case, is exactly the same used in the last step.
   III. When a sub-zone is selected, then the scan highlights first the cell with the highest probability of occupancy. If it is not selected, the scan passes to the next cell value. This routine keeps going on until a cell is selected. Once a position is selected, the probability value of the cell, sub-zone and zone is updated. The update of the probabilities values is made by the Bayes’ rule.

As it can be seen, the number of cells that belong to a sub-zone or a zone is variable. Then, the organization of the zones at robot’s workspace is dynamic. This allows improving the scan mode in order to access in a priority way to the most frequently used cells.

| Values | Definitions |
|--------|-------------|
| \( a \) | highest probability cell value |
| \( b \) | lowest probability cell value |
| \( \{ c_i : b + \frac{2}{3} (a - b) < P(C_i \mid G) \leq a \} \) | zone 1: the set of all cells which probabilities are the highest of the workspace |
| \( \{ c_i : (b + \frac{a - b}{3}) < P(C_i \mid G) \leq (b + \frac{2}{3} (a - b)) \} \) | zone 2: the set of all cells which probabilities are of middle range |
| \( \{ c_i : b \leq P(C_i \mid G) \leq (b + \frac{a - b}{3}) \} \) | zone 3: the set of all cells with the lower probability of the workspace |

3.6. Workspace probability update based on Bayes’ rule

The probability update of each cell at the workspace is based on the recursive Bayes’ rule. As was mentioned before, the workspace begins with an initial distribution of its cells. Once a cell is reached by the user, its probability value changes according to equation (3).

Let \( C \) be any cell at robot’s workspace and \( G \) a set to which that cell belongs. Thus, the updating algorithm is given by,

\[
P_t(C \mid G) = \frac{P_t(G \mid C)P_{t-1}(C \mid G)}{P_t(G \mid C)P_{t-1}(C \mid G) + P_t(G \mid \overline{C})P_{t-1}(\overline{C} \mid G)}
\] (3)
where terms in equation (3) can be read as shown in Table II.

| Terms | Definitions |
|-------|-------------|
| $P_k(C | G)$ | The probability of the cell $C$ given the set $G$ (to which it belongs) was selected, at instant $k$. |
| $P_k(G | C)$ | Is the probability of the whole group of cells $G$ (to which $C$ belongs) given the selection of $C$, at instant $k$. |
| $P_k(G | \overline{C}) = 1 - P_k(G | C)$ | Is the probability of group $G$ given the non-selection of cell $C$ at instant $k$. |
| $P_k(\overline{C} | G) = 1 - P_k(C | G)$ | Is the probability of non-selection of $C$ given the group $G$ at instant $k$. |

In this work, initial values of cells’ probabilities are taken, so $P(C)$ is defined for every cell. Besides, $P(G | C)$ at every instant is defined as,

$$P(G | C) = \frac{\sum P(C \in G)}{\# \text{of cells of the group } G}$$  \hspace{1cm} (4)

A more extended development of this algorithm can be seen at [14]. Once the updating algorithm is complete, the scan algorithm is released as was described in Section 3.5.

4. The complete system

The signals acquired by the electrodes (positions $O1$ and $O2$ of the international system 10-20 for allocating electrodes ([15]) are filtered and amplified by the BCI and then digitalized by the ADQ12 board.

Now, the signals are ready to be processed by the application software. When the application starts, a training/calibration phase is invoked ([15]). This phase is important to detect the current operator's ERD level, which changes constantly. An ERS level is established as a multiple (5 to 10 times) of the measured ERD level. This value should be reached by the operator so that the system recognizes a command. The operator must decrease his/her signal level under the established ERS level before generating a new command.

The probabilistic scan mode is released once the system is turned on. The scan will allow the BCI’s user to select a specific cell. When it is accomplished, the central coordinates of the cell are sent to the remote manipulator, via TCP/IP, and while movements are executed, encoder's information are sent back to the local server in order to provide a visual feedback (a representation of the manipulator's configuration on the screen) to the operator.

5. Conclusions

In this paper a workspace probabilistic scan mode system to teleoperate a manipulator using EEG signals through a TCP/IP channel was presented, which is an important application of EEG signals to command devices.

A way to command devices using only the operator's brain rhythms, even with simple EEG signals like ERD and ERS, was also shown. It is important to mention that electromyographic (EMG) and electrooculographic (EOG) signals were not used here.
The system presented here shows the versatility of the BCI used to command/control mechanical devices. In addition, the implementation of a non-common scan mode to operate the manipulator opens the door for continuing researching in this area.

References
[1] Kubler A, Kotchoubey B, Kaiser J, Wolpaw J R and Birbaumer N 2001 Psychol Bul 127 358-375
[2] Wolpaw J R, Birbaumer N, McFarland D J, Pfurtscheller G, and Vaughan T M 2002 Clin Neurophysiol 113 767-791
[3] Lehtonen J 2003 EEG-based brain computer interfaces Master's thesis, Helsinki University of Technology, Helsinki, Finlandia
[4] Felzel T 2001 On the possibility of developing a brain-computer interface (BCI) Technical University of Darmstadt, Darmstadt, Germany, Tech. Rep.
[5] Millán J, Renkens F, Mouriño J and Gerstse W 2003 Non-invasive brain-actuated control of a mobile robot Proceedings of the 18th International Joint Conference on Artificial Intelligence, Acapulco, Mexico
[6] Auat Cheein F A and Postigo J 2005 A fast finite state machine design for a brain computer interface XI Reunión de Trabajo en Procesamiento de la Información y Control, Argentina
[7] Auat Cheein F A and Postigo J 2004 Diseño de una máquina de estado finito gobernada por señales electromiográficas faciales 33 Jornadas Argentinas de Informática y Investigación Operativa, Argentina
[8] Haas S M, Frei M G, Osorio I, Pasik-Duncan B, and Radel J 2003 EEG ocular artifact removal through ARMAX model system identification using extended least squares Communications in Information and Systems 3 19-40
[9] Rohatova M, Sykacek P, Kosma M, and Dorffner G 2001 Detection of the EEG artifacts by the means of the (extended) Kalman filter Measurement Science Review 1
[10] Tirpak T M, Kadluczka M, Xiao W and Nelson P C 2004 A signal processing platform for brain-computer interface optimization. Motorola General Business Information (EAR99)
[11] Kelly R, Carelli R and Soria C 2004 Sobre control cinemático de impedancia en robots industriales IV Congreso Mexicano de Robótica, Mexico
[12] García L M J, Manchón R P and García O R 2000 Sistemas Informáticos de Tiempo Real. Spain: Ed. Universidad Miguel Hernández
[13] Ferreira A, Freire Bastos-Filho T, Sarcinelli-Filho M, Auat Cheein F A, Postigo J F, Carelli R 2006 Teleoperation of an Industrial Manipulator Through a TCP/IP Channel Using EEG Signals International Symposium of Industrial Electronics Montreal Proceedings of ISIE2006 1 3066-3071
[14] Elfes A 1989 Using occupancy grids for Mobile Robot perception and navigation. IEEE Computer Society 22 46-57
[15] Auat Cheein F A 2005 Diseño de una interfase cerebro-computadora para la navegación de un robot móvil Master's thesis, Facultad de Ingeniería de la Universidad Nacional de San Juan, San Juan, Argentina
[16] Ochoa J B 2002 EEG brain classification or brain computer interface, Master's thesis, Ecole Polytechnique Federale de Lusanne, Lusanne