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A collaborative and voice configured electric powered wheelchair control system based on EEG and head movement

Fatma BEN TAHER, Nader BEN AMOR, Mohamed JALLOULI, Aicha BEN HAMMOUDA, Olfa DGHIM
Computer and embedded system (CES)
Ecole Nationale d'Ingenieurs de sfax
University of Sfax, Tunisia

***Abstract*—The statistics realized in 2013 by the Ministry of Social Affairs, indicate that the rate of disability in Tunisia is estimated at 2%, 43.9% is a mobility impairment. A large number of them have a difficulty or are enable to use a usual electrical powered wheelchair. As a solution, some researchers replace the standard joystick by eye, voice, head, etc... control. In this paper, the purpose is to control the EPW using EEG signal and head movement to increase the system performance. The voice recognition is used to configure, activate and deactivate the control system.**

Keywords–EEG signal; head movement ; voice recognition ; EPW control; human-computer interaction

I. Introduction

Thanks to technological progress, the Electric Wheelchairs (EPW) has allowed many people with severe motor deficits to overcome their mobility handicap. This had a positive impact on their quality of life because of the various fields of activity become accessible. Despite the importance of wheelchairs, some types of motor disability are incapable to use usual EPW. In fact, According to experiments conducted with individuals with severe disabilities [1] in France, the use of power wheelchairs is very restricted and requires a personalization of the EPW. To allow these persons to regain independent mobility, many researchers were interested in the development of smart wheelchair by adding automatic features of the chair or by using alternatives methods of monitoring.
Our approach is to provide the EPW users an alternative way to control the EPW. The control of the EPW is entirely the responsibility of the user, the machine simply translate signals into commands. The proposed control system combines brain signals and head movement to provide a simple and reliable control. To configure the control interface, activate and deactivate the movement of the EPW, we propose the voice recognition to avoid a third part assistance.
This paper is structured as follows: section 2 describes a state of art of smart wheelchair. In section 3, the proposed methodology is described and section 4 reviews experiences and results. Finally, section 5 presents conclusion.

II. State of art

The field of robotics for disabled has seen progress in recent years. The aim is to facilitate handicapped persons lifes and help them to integrate the society. Many researches are interested in wheelchairs called "intelligent" inspired mainly from mobile robotics. Especially since the development of computer systems has provided new opportunities for research in the field of human-computer interaction

A. EEG based wheelchair system

Electroencephalography (EEG) is the recording of the electrical activity produced by neurons in the brain [2] [3]. Registration is obtained by placing electrodes on the scalp of a gel or a conductive paste. Usually used in medical field to detect brain anomaly, but recently used in robotic domain.

Minguez et al. [4] propose to make a virtual reconstruction of the displayed environment with a set of points in the free space that can be selected using P300 brain interface machine. The selected destination will be reached automatically.
In [5], Carlson et al. propose a shared control architecture that couples the intelligence and desires of the user with the precision of the EPW based on asynchronous motor imagery protocol. The user imagines the kinesthetic movement of the left hand, right hand or both feet, which gives three separate classes. During the training process, the authors select the two most discriminable classes to provide reliable mapping to control actions. When one of these navigation commands is not provided by the user, a third non-voluntary control implicit class exists.
In [6], EEG signals are used to detect the direction of the eyes to control the EPW. Indeed, Tran et al. propose an algorithm that processes online EEG signals to control the chair in real time. Experimental results have shown that the accuracy rate is 82.6% in the indoor environment.
Some researchers believe that EEG wheelchair control is the best and the safest way to help completely paralyzed person to gain their independence. These projects could be seen as a good starting point for future applications although they lack maturity and the bulkiness of headset also constitutes a major problem.

B. Head movement based wheelchair

In field of head movement recognition there are two main techniques: the first is based on computer vision techniques, it needs a camera and preferably a very powerful computer and the second is based on sensors placed on the user's head.
Pajkanovic et al. detect in [7] the movement of the user's head by placing an accelerometer on the user's head. The system offers 4 different directions to the user. First, the gravity component must be removed. To have optimum values the authors apply a low pass filter to output values of the accelerometer. The setting of thresholds that represent the four corners of possible directions is done before starting the driving. To deliver the perfect control: the user begins to lean his head towards the desired direction then turns his head to the first position and then revisit his head.

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In [8], Berjon el al. propose to move the chair using a camera connected to a laptop to track the face of the person sitting in the wheelchair. For this, the Haar-like features are used with the optical flow algorithm [9].
Generally a head movement tracking system based on computer vision must face several constraints:

- What to do when the head comes out of the camera's field?
- Can we install the system on the chair?
- How to deal with light variations?
- How to detect head motion for people with different appearances?

Techniques based on the use of sensors must respect the constraints of cost, simplicity and robustness.

C. *Voice recognition based wheelchair*

In [10], authors present voice controlled EPW. Input signal using a headphone was processed with Matlab then transmitted to the processor.
A Speed Control of Wheel Chair for Physically Challenged Using Arduino was presented in [11], voice is provided to the Arduino which is a Microcontroller used to control the motion of wheelchair. HM 2007 is used for voice recognition purpose. The Arduino controls the movement of wheelchair based on the input signal received.
Another proposal in [12] uses voice to control the EPW. In fact, the EPW is controlled through the voice command and a reactive fuzzy logic controller to overcome low sound. HM 2007 IC is used for the voice recognition purpose.
The major inconvenient of voice based control is the noise when navigating in outdoor environment. Which reduce the accuracy rate of voice based techniques.

D. *Multi modal control techniques*

Data fusion integrates data from multiple sensors to provide better analysis and decision; it provides a better result because the strengths of one type can compensate for the weaknesses of another type. In literature the combination of EEG with other source like eye tracking was to control robotic system without using data fusion techniques to ameliorate system control [13]
EEG and gyroscope signals can be most effectively combined to provide a more accurate detection of head-movement artifacts in the EEG. To this end, several methods of combining these physiological and physical signals at the feature, decision and score fusion levels are examined. Results show that combination at the feature, score and decision levels is successful in improving classifier performance when compared to individual EEG or gyroscope classifiers [14]
According to previous works, multi-modal control ameliorates the system performance compared to the one source control. But, in our knowledge data fusion techniques between EEG and head movement was not used on controlling an EPW even that EEG and head tracking were previously used in robotic system. To configure and activation/deactivation the control system without a third part assistance, the voice recognition was used.

III. Wheelchair navigation system

Our technique offers three different ways to control the wheelchair: EEG signals, head movement and EEG/head fusion. In this section, each technique will be presented. As this system target persons with severe motor disability the system configuration is done via voice recognition

A. *The Emotiv EPOC headset*

To acquire EEG signals, we have used the EEG headset Emotiv EPOC(Figure 1(a)) [15]. It has the ability to provide expressive, cognitive and emotional information (Figure 1(b)). It does not need the assistance of a medical staff or gel application on scalp. The headset has a lithium battery that provides 12 hours of continuous use. The neuroheadset acquires brain Neuro-signals with 14 saline sensors placed on the users scalp. It also integrates two internal gyroscopes to provide users head position information. The communication of this device with a PC occurs wirelessly by means of a Bluetooth USB dongle. Emotiv provides software in two ways: (i) developed applications (Control Panel) are provided with graphical interface to process brain signals, to train the system, and to test the neuroheadset; and (ii) an application programming interface (API) to allow users to develop C or C++ software to be used with the neuroheadset Emotiv

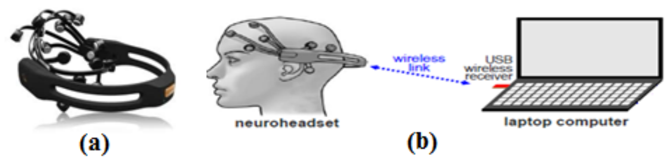

Figure 1. (a) EMOTIV Epoc neuro-headset (b) connection between epoc headset and the pc

delivers the Emotiv API in the form of a dynamically linked library (dll). Emotiv Control Panel (Figure 2(a))provides a GUI (graphical user interface) that interfaces with Emotiv EmoEngine through the Emotiv API. The Control Panel user interface showcases the EmoEngine's capabilities to decipher brain signals and present them in useful forms using Emotiv's detection suites. The Cognitiv Suite panel (Figure 2(b)) uses

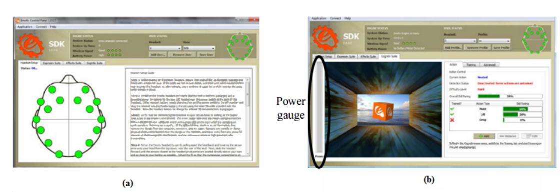

Figure 2. (a): EMOTIV control panel (b) Cognitiv suite panel

a virtual 3D cube to display an animated representation of the Cognitive detection output. This 3D cube is also used to assist the user in visualizing the intended action during the training process. The Power gauge to the left of the 3D display is an indicator of the "action power", or relative certainty that the user is consciously visualizing the current action

B. *Control technique description*

Once our application (Figure 3) is connected to Emotiv control panel via Emotiv API the user could:

- have all the information about the signal quality, the battery level, the control mode, etc.
- choose the control mode from 5 choices: Expressive, cognitive, Expressive/cognitive, head movement and fusion mode
- chooses the desired language: Arabic, French and English

To avoid a third part assistance when using the control interface all the needed configuration are done using Windows Speech Recognition integrated in Visual Studio 2008. Also, the activation or deactivation of the interpretation is done using voice commands.

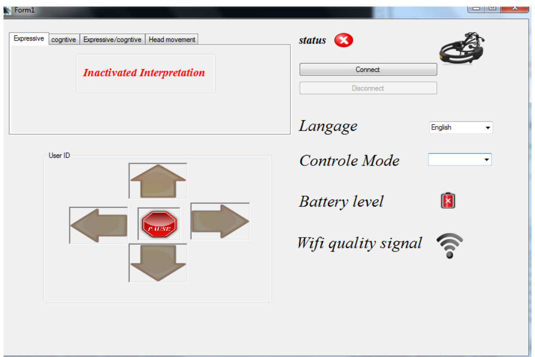

Figure 3. The Control technique interface

1) EEG based modes: The EEG control technique offers 3 control modes [16]: Expressive mode, cognitive mode and Expressive/cognitive mode. Each mode offers the possibility to control the electric wheelchair with an easy and safe way.

- **Expressive mode** The expressive mode use eye direction (right and left) and face expression like brow and lips to control the EPW. Once the expressive interpretation is activated, it will be possible to control the chair.
  - To turn to the left the user must fix his gaze on the left
  - To turn to the right the user must fix his gaze on the right
  - To go forward the user has to raise or furrow his brow
  - To go backward the user has to smirk to the left or to the right
- **Cognitiv mode** Before using this mode a training step is needed using the Cognitiv Suite panel. In fact this mode uses cognitive data detected via the Emotiv headset to control the wheelchair. So the user has to think about the action that he desires to do: turn left/right, go forward/backward. To increase the user safety the concentration rate and the action power must be more than 50%.
- **Exressiv/Cognitiv mode** This mode presents the combination between the expressiv and the cognitiv mode. To move the chair for example forward the user must raise or furrow his brow and think about the desired action with a concentration rate more than 50%.

2) Head movement command mode: This mode uses the Emotiv Headset gyroscope which indicates the head position at any time. In order to convert the head position in command for the EPW, the control system must follow several steps:

- **Head position calibration:** The first step in this technique is the calibration of the position of the head. For this the user must maintain stationary head to the end this step. The end of this stage will be indicated by a feedback in the graphical interface and a beep too. Indeed, the aim is to find the position $(x, y) = (0, 0)$ (figure 4) for the control system through a function of the SDK EPOC headset.

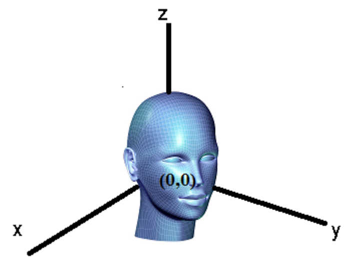

Figure 4. Head position calibration

- **Threshold values calibration:**
  In this mode, 9 threshold values must be fixed, 2 for each direction:
  - $th_F min$ et $th_F max$: the minimum and maximum threshold the forward direction
  - $th_B min$ et $th_B max$: the minimum and maximum threshold the backward direction
  - $th_R min$ et $th_R max$: the minimum and maximum threshold the right direction
  - $th_L min$ et $th_L max$: the minimum and maximum threshold the left direction

  To set the threshold values, the system prompts the user to lean his head slightly toward a specific direction and then to return to the starting position, then the user must increase the angle of leaning of the same direction and then return to the starting position. This will be done for each direction of the 4 possible directions.
- **Reading and interpreting the values of the position of the head:**
  Once the threshold values are set, the system's interpretation of the head movements begins. On each modification of the head position, the values of the x and y positions will be supplied to the system which in his turn classifies these values into three subsystems, Figure 5 illustrates the movement of head forward
  - If the values of x or y is between 0 et th_{min} then the value will be considered as a valid value but does not influence the system behavior to ensure stability.
  - If the values of x or y is between th_{min} et th_{max} then the value will be considered as a valid value and influences the system behavior. Hence to control the wheelchair, it must:

- $y \in [th_F min, th_F max]$ to move forward
- $y \in [th_B min, th_B max]$ to move backward
- $x \in [th_R min, th_R max]$ to turn to the right
- $x \in [th_L min, th_L max]$ to turn to the left

◦ If the value of x or y is above th_{max} then the value will be considered as invalid value and the system disables the interpretation and requires calibration of the position of the head.

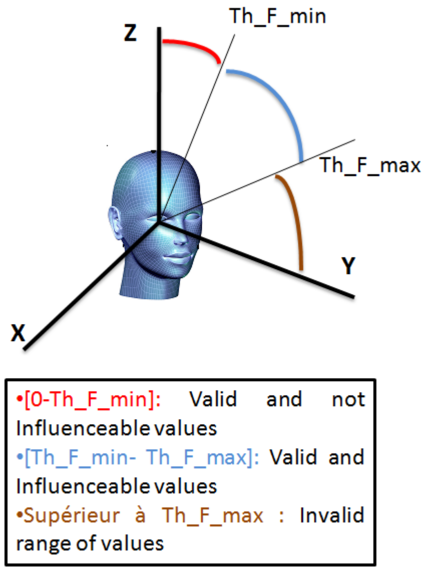

Figure 5. Interpretation sample of head position values

To maintain system stability and hardware performance, we chose to return to the "Stop" state after each movement. For example, if the user moves his head forward to move forward the chair, and then moves his head directly to the right, the system interprets this movement as a stop command.

3) Fusion control mode: Data from different mode can be fused at both the feature level and the decision level. In this paper, we applied these two fusion strategies and evaluated their performance.
For feature level fusion, each variable in each vector will be considered as clue of the desired direction to form the final vector V_{fusion}. Initially, each element in V_{fusion} is equal to zero. Then, the correspondent element in V_{fusion} will be increased. For example, if eye direction is left then $V_{fusion}(4) = V_{fusion}(4) + 1$. The final decision will be the maximum element in V_{fusion}.

$$V_1 = \begin{pmatrix} Eye\ direction \\ BROW\ State \\ SMIRK\ State \\ Cognitive\ action \\ Cognitive\ action\ power \\ Concentration\ degree \end{pmatrix} V_2 = \begin{pmatrix} X\ head\ position \\ Y\ head\ position \\ Calibration\ state \end{pmatrix} \tag{1}$$

$$V_{fusion} = \begin{pmatrix} forward \\ backward \\ stop \\ left \\ right \end{pmatrix} \tag{2}$$

For decision level fusion, each mode operates separately and delivers its own decision. We was inspired from the voting theory [17] to find the final decision. If the three modes give three different decisions then the final decision is "Stop".

IV. RESULTS

The objective of this study was to assess the performance and adaptability of the single and multi sources control techniques of an EPW. All our candidates are healthy, aged between 25 and 35 and none of them had ever utilized an electric wheelchair before. In this paper, a 3D wheelchair movement simulator realized in our laboratory was used for experimental validation. The candidates start with getting used to the 3D simulator, rooms, wall, etc. The objective is to command the wheelchair from the principal door to the principal bedroom (figure 6) and evaluate the time and the rate error for each control technique.

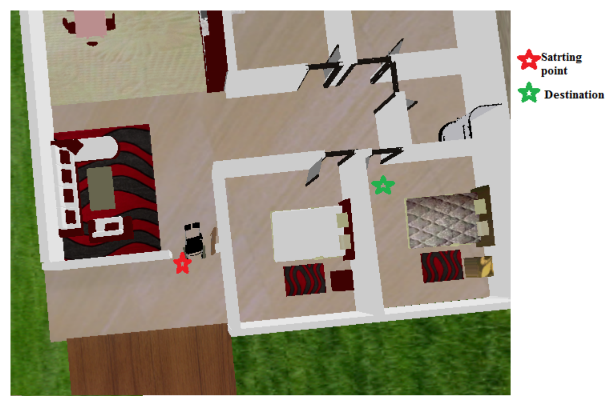

Figure 6. Users objective

The main observation in this experiment was that users could actually control the wheelchair in the 3D simulator, independently of control mode, and with just a small amount of practice. This is indicated by the low error rate (table I).

In separate control technique the EEG signals movement with cognitive mode was judged significantly more reliable than the others and the head movement technique was rated slightly easier.

When using data fusion technique especially with feature level, error rate was decreased. However, the time needed to reach the destination has augmented. This may be explained by the time required for the fusion.

TABLE I. Performance evaluation of wheelchair control techniques

Used Technique	% accuracy	Mean Time (sec)
EEG expressive	85	77
EEG cognitive	86.32	90
EEG expressive/cognitive	88.32	90
Head movement	71.65	54
Fusion (feature level)	91.33	95
Fusion (decision level)	90.64	92

TABLE II. Multi sources based technique comparison for EPW control

Used Technique	% accuracy
[18]	80
[19]	88.66
The proposed technique	91.33

Finally, we compared the proposed fusion technique with other technique based multi sources. Table II shows that the proposed control technique based on the fusion guarantee good results against other techniques.

V. Conclusion

In this paper, we have presented different techniques to control an EPW via EEG signal and head movement. For data acquisition we have used a low cost and non invasive headset (EPOC). To reduce the error rate when using single source control technique, we have proposed a data fusion technique using two fusion levels: feature and decision levels. We succeeded to get better control results and reduce error rate. Our work aims to realize news techniques to control EPW for severely disabled persons without risking their security, give them the opportunity to gain their autonomy.

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