Control of a Smart Home with a Brain-Computer Interface

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Abstract

An electroencephalogram (EEG) based brain-computer interface (BCI) was connected with a Virtual Reality system in order to control a smart home application. Therefore special control masks were developed which allowed using the P300 component of the EEG as input signal for the BCI system. Control commands for switching TV channels, for opening and closing doors and windows, for navigation and conversation were realized. Experiments with 3 subjects yielded accuracies of the BCI system between 83 and 100 % and showed that such a BCI system can be used for smart home control. The Virtual Reality approach is a very cost effective way for testing the smart home environment together with the BCI system.

1 Introduction

An EEG based Brain-Computer Interface (BCI) measures and analyzes the electrical brain activity (EEG) in order to control external devices. BCIs are based on slow cortical potentials [1], EEG oscillations in the alpha and beta band [2, 3], the P300 response [4] or steady-state visual evoked potentials (SSVEP) [5]. BCI systems are used mainly for moving a cursor on a computer screen, controlling external devices or for spelling purposes [2, 3, 4].
BCI systems based on slow cortical potentials or oscillatory EEG components with 1-5 degrees of freedom were realized up to now. However, high information transfer rates were reached based on 2 degrees of freedom as otherwise the accuracy of the BCI systems dropped down. SSVEP based systems allow selecting up to 48 different targets and are limited by the number of distinct frequency responses that can be analyzed in the EEG. P300 response based BCIs typically used a matrix of 36 characters for spelling applications [4].

2 Methods

Three subjects participated in the experiments and were trained firstly in spelling characters and numbers based on their P300 EEG response. Therefore, the characters of the English alphabet (A, B,…Z) and Arabic numbers (1, 2,…9) were arranged in a 6 x 6 matrix on a computer screen. Then the characters were highlighted in a random order and the subject had the task to concentrate on the specific character he/she wanted to spell. All experiments were undertaken in 2 modes: (i) the row/column speller – all items of one row or column are highlighted at the same time, (ii) the single character speller – only one character is highlighted. For the single character speller each character was highlighted 15 times. For the row/column speller each row and each column was also highlighted 15 times. This results in a speed up of 3 for the row/column speller. Another important parameter in the P300 experiment is the flash time (character is highlighted) and the dark time (time between 2 highlights). Both times should be as short as possible to reach a high communication speed, but must be long enough so that the subject can detect the flash and that the single P300 responses are not overlapping.

At the beginning of the experiment the BCI system was trained based on the P300 response of 42 characters of each subject with 15 flashes per character (about 40 minutes training time). All 3 subjects needed between 3 and 10 flashes (mean 5.2) per character to reach an accuracy of 95 % for the single character speller and between 4 and 11 flashes (mean 5.4) for the Row/Column speller. This resulted in a maximum information transfer rate of 84 bits/s (60 ms per character flash time) for the single character speller and 65 bits/s (100 ms per character flash time) for the row column speller.

Then the P300 based BCI system was connected to a Virtual Reality (VR) system. A virtual 3D representation of a smart home with different control elements was developed as shown in Figure 1.

Figure 1: Virtual representation of a smart home

In the experiment it should be possible for a subject to switch on and off the light, to open and close the doors and windows, to control the TV set, to use the phone, to play music, to operate a video camera at the entrance, to walk around in the house and to move him/herself to a specific location in the smart home. Therefore special control masks for the BCI system were developed containing all the different necessary commands. In total 7 control masks were created: a light mask, a music mask, a phone mask, a temperature mask, a TV mask (see Figure 2, left), a move mask and a go to mask (see Figure 2, right).

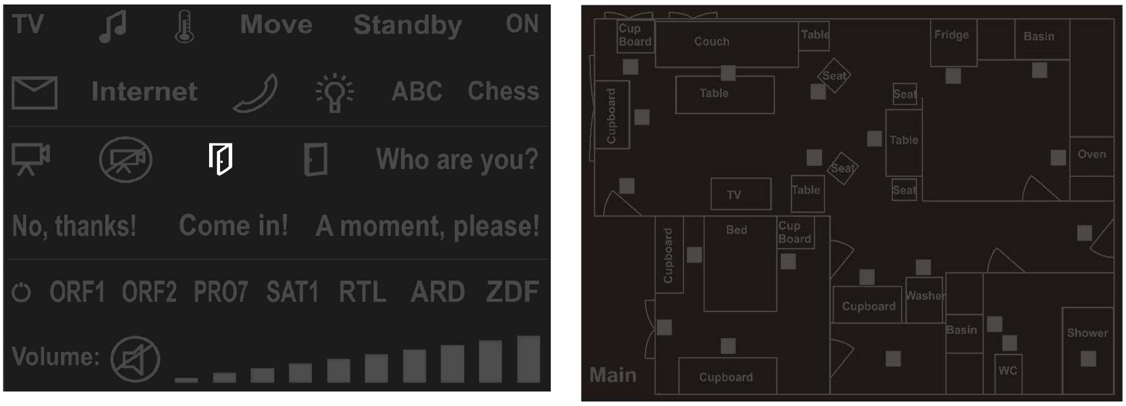

Figure 2: Left: Control mask with the main menu in the first 2 rows, the icons for the camera, door control and questions in the 3rd and 4th row and the TV control in the last 2 rows. Right: Control mask for going to a specific position in the smart home.

The experiment for the P300 smart home control was divided into 3 parts with 15, 11 and 16 decisions respectively. One task was e.g. to go to the living room, to switch on the TV and to select a specific channel, …

3 Results

Table 1 shows the results of the 3 subjects for the 3 parts of the experiment and for the 7 control masks. Interestingly, the light, the phone and the temperature mask were controlled by 100 % accuracy. The Go to mask was controlled with 94.4 % accuracy. The worst results were achieved for the TV mask with only 83.3 % accuracy.

Mask	**Part1**	**Part2**	**Part3**	**Total**
Light	100%	100%	100%	100%
Music	-	89,63%	-	89,63%
Phone	-	100%	-	100%
Temperature	100%	-	-	100%
TV	83,3%	-	-	83,3%
Move	88,87%	-	93,3%	91,1%
Go to	100%	-	88,87%	94,43%

Tab 1. Accuracy of the BCI system for each part and control mask of the experiment for all subjects.

Table 2 shows the number of symbols for each mask and the resulting probability that a specific symbol flashes up. If more symbols are displayed on one mask then the probability of occurrence is smaller and this results in a higher P300 response which should be easier to detect. The flashes column shows the total number of flashes per mask until a decision is made. The translation time per character that is longer if more symbols are on the mask.

Mask	Symbols	Probability [%]	Flashes	Time per character [s]
Light	25	4	375	33,75
Music	50	2	750	67,50
Phone	30	3.3	450	40,50
Temperature	38	2.6	570	51,30
TV	40	2.5	600	54,00
Move	13	7.7	195	17,55
Go to	22	4.5	330	29,70

Tab 2. Number of symbols, occurrence probability per symbol, number of flashes per mask (e.g. 25 x 15 = 375) and conversion time per character for each mask.

4 Discussion

The P300 based BCI system was successfully used to control a smart home environment with an accuracy between 83 and 100 % depending on the mask type. The difference in accuracy can be explained by the arrangement of the icons.

However, the experiment yielded 2 important new facts: (i) instead of displaying characters and numbers to the subject also different icons can be used, (ii) the BCI system must not be trained on each individual character. The BCI system was trained with EEG data of the spelling experiment and the subject specific information was used also for the smart home control. This allows using icons for many different tasks without prior time consuming and boring training of the subject on each individual icon. This reduces the training time in contrast to other BCI implementations were hours or even weeks of training are needed [1, 2, 3]. This reduction in training time might be important for locked-in and ALS patients who have problems with the concentration over longer time periods. The P300 concept works also better if more items are presented in the control mask as the P300 response is more pronounced if the likelihood that the target character is highlighted drops down [4]. This results of course in a lower information transfer rate, but enables control of almost any device with such a BCI system. Especially applications which require reliable decisions are highly supported. Therefore the P300 based BCI system is an optimal tool for the smart home control. The virtual smart home acts in such experiments as a testing installation for real smart homes. Also wheelchair control, which many authors identify as their target application, can be realized with this type of BCI system in a goal oriented way. In a goal oriented BCI approach it is then not necessary e.g. to move a robotic hand by thinking about hand or foot movements and controlling right, left, up, down commands. Humans just think “I want to grasp the glass” and the real command is initiated by this type of BCI implementation.

5 Conclusions

A P300 based BCI system is optimally suited to control smart home applications with high accuracy and high reliability. Such a system can serve as an easily reconfigurable and therefore cheap testing environment for real smart homes for handicapped people.

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