Clinical Evaluation of a hybrid-BCI text-entry system

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Abstract. This work presents mid-term clinical evaluation results of a hybrid Brain Computer Interface (BCI) text-entry prototype based on Motor Imagery. This novel prototype takes advantage of a simplified graphical interface, tight coupling of inference mechanisms and the Human-Computer Interface (HCI) and an auxiliary hybrid control modality which exploits potential residual muscular activity, in order to improve end-user experience compared to earlier text-entry system designs. The results of clinical testing with three disabled and one healthy user in a word-typing task demonstrate the effectiveness and efficiency of this prototype.

Keywords: hybrid BCI, Motor Imagery, EEG, EMG, text entry, clinical evaluation

1. Introduction

Brain-Computer Interaction (BCI) technology has emerged as a promising solution for enabling communication capabilities to people with motor function impairments. To investigate its prospects, a self-paced, non-invasive, electroencephalography (EEG) – based, Motor Imagery (MI) BCI has been integrated into the commercially available, Assistive Technology (AT) software QualiWORLD (QualiLife SA, Switzerland), thus demonstrating the possibility of enriching existing AT with the novel BCI channel for text-entry purposes [Perdikis et al, 2010]. Despite succeeding in the aforementioned proof of concept, and following a user-centered approach, the design of the MI text-entry prototype has been revisited to incorporate the end- and professional user feedback resulting from initial clinical evaluation. More specifically, end-user testing of the QualiWORLD (QW) prototype revealed the following shortcomings: i) The complicated QW Graphical User Interface (GUI) imposed excessive mental workload. ii) The QW control paradigm [Perdikis et al., 2010] demands excessive Intentional Non-Control abilities (INC, [Tavella et al., 2010]). iii) No appropriate error-handling mechanism existed. iv) No predictive text technologies facilitated the user's task.

These limitations led to only one out of two end-users being able to complete a spelling protocol despite substantial efforts. Our new prototype alleviates all the above-mentioned limitations to better accommodate the user needs, a fact reflected in the improved results of the latest clinical evaluation.

2. Materials and Methods

The new BrainTree prototype employs an asynchronous 2-class Motor Imagery BCI as the main control modality, enabling the user to deliver two types of commands (left/right) by performing two different MI tasks for controlling a binary text-entry application (EEG monitoring with a gTec gUSBamp amplifier, channel configuration and EEG processing identical to [Tonin et al., 2011]).

The main novelties of BrainTree lie on the tight integration of inference mechanisms with the HCI and the multi-modal control paradigm. Concerning the former, the user observes a simplified GUI (Fig.1) where all available characters (Latin alphabet, space and backspace) are alphabetically arranged. This visualization is a clear representation, using underlying inference mechanisms based on a Hu-Tucker binary tree, which ensures the minimum average number of commands needed to reach a character (leaf nodes of the tree) based on a prefix-based Language Model (LM), while preserving the alphabetic order of characters to simplify the visualization and reduce the user's mental workload.

The user's intentions are continuously illustrated in a conventional MI BCI feedback (Fig. 1: bar underneath the character bar), where a left/right command is enabled when the light-colored “liquid” (overlayed on the dark-colored feedback background) fills the respective side of the feedback bar. BCI commands result in the respective move of the vertical cursor which denotes the current node in the tree (Fig. 1: cursor between “q” and “r”), which allows the user to descend the binary tree structure through the BCI, until a leaf node is reached and the associated character is typed. This paradigm completely eliminates waiting intervals, thus rendering INC skills redundant. A 3 seconds-long pause is interleaved between consecutive commands. A “bubble” surrounds the currently available characters (current left/right subtrees, Fig 1: bubble surrounds “opqr”), informing about previous erroneous command(s), that need to be “undone” by ascending the tree an appropriate number of times.
To easily achieve the latter, the control paradigm is enhanced with an effective error-handling mechanism, where electromyography (EMG) monitoring (using a second synced gUSBamp) from a single channel allows the user to “undo” the latest BCI action (by ascending to the parent node) through a brisk movement, exploiting the potential existence of the user's muscle residual ability. In case the user's level of disability does not allow the use of this hybrid component, the Backspace functionality can be used instead in a purely BCI-actuated fashion. The EMG-actuated correction can be consecutively used to “undo” more than one of the latest BCI actions, since a full history of those is saved at runtime.

3. Results

Three end-users (E1-3, C6-quadruple) and one healthy user (H1) completed a spelling protocol consisting of the words: hello, email, computer, internet. Table 1 summarizes their performances using i) the full BrainTree functionality and ii) disabling the LM (uniform probability distribution of characters). Performances are compared to a manual control baseline, where button-presses replace EEG/EMG commands.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Time / Character (sec)</th>
<th>Time / Character (%)</th>
<th>Time/Character, no LM (%)</th>
<th>#Undos / Character</th>
<th>#Undos / Character, no LM</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>55 ± 12</td>
<td>342</td>
<td>330</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>E2</td>
<td>44 ± 12</td>
<td>275</td>
<td>323</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>E3</td>
<td>49 ± 7</td>
<td>306</td>
<td>560</td>
<td>1.2</td>
<td>3.4</td>
</tr>
<tr>
<td>H1</td>
<td>33 ± 5</td>
<td>203</td>
<td>516</td>
<td>0.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Mean (E)</td>
<td>49</td>
<td>308</td>
<td>404</td>
<td>1.1</td>
<td>1.7</td>
</tr>
</tbody>
</table>

4. Discussion

All subjects completed the protocol in 2-3 BCI sessions, which already represents an important improvement over our previous efforts. The average time needed per character across end-users was 49 sec, smaller than that achieved by a single end-user with the QW prototype and around 3 times slower than the manual modality. Typing speed varied across subjects and words due to fluctuating BCI performances, the fastest word trials approaching 30 sec/char. Users moderately employed the EMG-activated hybrid correction (once per character/~5 BCI commands), showing that hybrid-BCI error-handling can be very efficient without wearing out subjects with limited and impaired muscular abilities. This figure almost doubles in the case where the language model is disabled, demonstrating the fact that HCI intelligence can help the user avoid errors by facilitating the task, while also speeding it up (Table 1). Our future work will focus on clinical evaluation with more end-users, improved HCI aspects and adaptive BCI approaches.

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References

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