A Rehabilitative Eye Tracking-Based Brain-Computer Interface for the Completely Locked-In Patient

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INTRODUCTION

Despite contemporary advancements in healthcare, conventional methods of treatment have more than once proved ineffective in curing certain classes of neurological disorders, especially those where the central nervous system has been subjected to severe irreversible damage. Such disorders include, but are not limited to, cerebral palsy, cerebral aneurysm, traumatic brain injury, stroke, apraxia, and aphasia. In certain severe cases, more than one disorder might affect the same patient, making him or her completely locked-in—that is, cognitively intact, but unable to move or communicate (Kennedy & Adams, 2003).

A completely locked-in patient usually suffers from symptoms that include complete inability of controlling any voluntary muscles in the body, apart from those needed for eye movements and blinking. Nonetheless, the patient is capable of reasoning, thinking, as well as preserving all signs of consciousness. Moreover, normal sleep and wake cycles persist throughout the locked-in state. In addition, as is the case of most paralyzed people, a locked-in patient has the tendency to develop muscle atrophy and spasticity. Figure 1 illustrates a sketch of a locked-in patient.

There are vast regions around the world where the completely locked-in patient is doomed to social rejection—in particular, when conventional rehabilitation methods fail to lessen the severity of the patient's handicap. For example, in the absence of motor control, it is practically impossible to use sign language or common input devices to interface with a computer system in order to communicate through spelling or expression-building software (Betke, Gips, & Fleming, 2002).

This article describes the design and development of a low-cost eye tracking-based brain-computer interface system for the rehabilitation of the completely locked-in patient having an intact ocular motor control to serve as an alternative means of communication (Abu-Faraj, Mashaalany, Bou Sleiman, Heneine, & Katergi, 2006). The developed system has been designed according to the following criteria: low cost, low processing power, simplicity of operation, little training requirements, minimal disturbance to the patient, and ease of customization to any mother tongue.

BACKGROUND

Brain-computer interface (BCI) methods for the rehabilitation of patients with neural disorders, similar to those previously listed, have been widely published. BCI systems are primarily classified according to the input technique utilized. Commonly reported techniques include electromyography (EMG) (Nagata, Yamada, & Magatani, 2004), electroencephalography (EEG) (Pfurtscheller, Müller-Putz, Pfurtscheller, & Rupp, 2005), electrooculography (EOG) (Barea, Boquete,

Figure 1. A sketch of a locked-in child
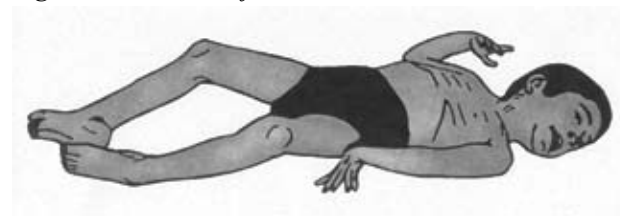
Mazo, & López, 2002), eye tracking (Amarnag, Kumaran, & Gowdy, 2003; Betke, Gips, & Fleming, 2002; Böhme & Barth, 2005; Cui, Ma, Wang, Tan, & Sun, 2004; Lee & Galiana, 2005; Li, Winfield, & Parkhurst, 2005; Yu & Eizenman, 2004), and other custom-designed input devices (Chen, 2001; Chen, Tang, Chang, Wong, Shih, & Kuo, 1999). The decision about which input technique to be used depends on the specific case being studied (Kennedy & Adams, 2003).

The EMG-based BCI requires that the patient be able to control at least one to three distinct muscles in order to be functionally effective, while the head-mounted tilt sensor method (Chen, 2001) can be used only if the patient has the voluntary ability of rotating his or her head. Accordingly, these two methods are precluded from consideration, since a locked-in patient does not possess any perceptible movements or EMG activity. Consequently, BCI methods employing eye tracking, EEG, or EOG remain possible for applications involving a locked-in patient (Kennedy & Adams, 2003). Nevertheless, EEG systems are expensive, sophisticated, cumbersome, and necessitate extensive training, while EOG methods suffer from inaccuracies at the extreme position of the pupil—particularly, small angle displacements (less than 2˚) are difficult to record, whereas large eye movements (greater than 30˚) do not produce bioelectric amplitudes that are strictly proportional to eye position (Clark, 1998). Hence, eye tracking systems would be more adequate for such applications, and are easier to setup.

THE EYE TRACKING BCI SYSTEM

The core of this work was to implement a fully functional rehabilitative system, while maintaining the development cost to a bare minimum. For this reason, the design specifications and requirements of the hardware were not only reduced, but also compensated for by the software program.

Hardware Description

A Genius® (KYE Systems Corp., Chung, Taipei Hsien, Taiwan, R.O.C.) Web cam was utilized and found suitable in terms of resolution, light sensitivity, and acceptable cost. The external packaging of the camera was redesigned, thereby substantially reducing its weight and volume, in order for it to be mounted on the patient's head. This alteration produced a headset consisting of a simple mechanical framework that separates the camera lens from the patient's eye by about five centimeters. The Web cam was connected to a notebook computer via a regular USB 2.0 port. The computer used in the development and testing of this system was a Toshiba Satellite™ M70-122 (Toshiba America, Inc., New York, NY, USA) notebook with a 1.73 GHz Centrino™ (Intel, Santa Clara, CA, USA) processor, 512 MB of RAM, and a 15 in. widescreen. Figure 2 shows a normal child instrumented with the eye tracking system.

Figure 2. A normal child instrumented with the eye tracking system

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