

Controlling a Computer Using Signals Originating from Muscle Contractions

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Abstract – *The idea for an interface allowing to communicate with a computer by certain muscle contractions – i.e. by wilfully altering the muscle tone – is presented. Such a system would make it possible to perform all sorts of computer-controllable actions just by raising the eyebrow, i.e. almost effortlessly. Possible applications include writing e-mails, navigating in a web browser, or working with various software applications. The muscle contractions can be detected in a robust way, almost insensitive to any kind of noise, so an interface device based on the muscle tone could also be used to control moving objects, such as a mobile robot or an electrical wheelchair, which could be of great help for persons with disabilities. Of course, this might offer an alternative for able-bodied persons as well, e.g. for controlling home entertainment appliances like TV sets or CD players.*

Keywords – *Human-Computer Interaction, Brain-Computer Interface, EEG Analysis, Biosignal Interpretation, EMG Signal.*

1 Introduction

The standard way of *communicating* with a computer is by using a keyboard and a mouse. This requires the reliable use of the hands, though, and is therefore inappropriate for persons suffering from severe physical disabilities.

Some neurological diseases, e.g. amyotrophic lateral sclerosis (ALS), can end in a so-called “locked-in” state, a situation where *a patient’s mobile mind is locked in an immobile body*. In addition to not being able to use their hands, those patients are unable to speak, so any kind of voice recognition system cannot improve their situation either.

Biosignal interfaces – allowing to control a computer by intentionally altering certain signals

associated with different bodily functions – represent *alternative* communication channels.

It will be shown in this paper that an interface based on muscle contractions requires the reliable control over one single muscle only. If a patient can produce a simple muscle tension at will, e.g. by clenching the teeth, raising the eyebrow or blinking with the eye, he or she is able to use the kind of systems laid out here.

This means that such a system represents an effective alternative for physically disabled people. In addition, as will also be discussed below, a muscle-based interface system can be an assistive device for able-bodied persons, with an ample number of possible applications.

The remainder of this paper is organized as follows. Section 2 contains a discussion of related work and is designed to further motivate why there is a need for a new kind of biosignal system. Section 3 presents the architecture of a biosignal interface in general and the idea for a system based on muscle control in particular. Section 4 then talks about possible target applications of such a system, and section 5 concludes the paper with a short summary and some thoughts on future work.

2 Related Work

A number of alternative input methods, which somehow deviate from the standard keyboard and mouse approach, have been reported in the literature.

The purpose of any such device is to provide a way of communicating with a computer without the use of the hands. The input channel for such an alternative interface is often based on time se-

ries representing measurements of certain biological functions. The most important *biosignals* in this respect are related to brain-waves (measured e.g. with an EEG machine) and eye movements (which are the source of EOG signals).

The first and most popular example is represented by a so-called brain-computer interface (BCI), i.e. a system inspecting the brain-electrical activity (the EEG) of a subject and generating output commands based on patterns recognized by a computer (the idea having its origin in [1]).

There are many groups of researchers dealing with the development of a BCI, and the number of such groups seems to grow every year (e.g. [2, 3, 4, 5, 6]).

For instance, the group around Wolpaw and McFarland [7, 8] developed a BCI based on the 8–12 Hz mu rhythm activity in the EEG. They made use of the fact that humans are able to (learn to) control their mu rhythm. The amplitudes of the mu rhythm recorded from subjects' scalps were translated into one- or two-dimensional cursor movements (on a video screen) – with an accuracy of at most 70% in the two-dimensional case.

Another approach is the work of Birbaumer et al. [9] which records and analyzes the EEG of a subject. That device tries to detect slow cortical potentials (SCP's) – representing a certain kind of polarizations in the EEG – and since humans can learn to regulate their SCP's voluntarily after prolonged bio-feedback training, the subject can intentionally select characters by varying his or her brain-waves (see also [10]). The system is very sensitive to noise, though, and a lot of care has to be taken in order to cope with that [11].

Pfurtscheller and his colleagues [12, 13] used neural network classifiers to analyze the subject's EEG activity. The network's task was to find out which of three different movements was performed (or only “mentally” planned) by the subject. In order to optimize classification accuracy, they had to discard EEG segments contaminated by all sorts of muscle contraction artifacts.

Anderson et al. [14] (see also [15]) also use a neural network classifier to determine which one of five different mental tasks a subject is performing. Their idea was to enable the subject to communicate with a computer by composing sequences of mental states – the classification accuracy of

73% or less on untrained segments was rather poor, though.

Anyway, as the EEG is extremely sensitive to noise (even the slightest movement of head, eyes or facial muscles, even the smallest change in the environment – e.g. another person passing by, a moving elevator several feet away – changes the EEG, which measures extremely tiny potential differences, considerably), an EEG-based interface is *not* suitable for *moving* applications (involving the subject moving too), such as a wheelchair control system. The sensitivity of the EEG signal is documented in the next section (fig. 2).

As already mentioned above, another class of biosignal interfaces is given by systems controlled by eye movements. Degermann et al. [16] describe a system called “Eyegaze” that enables the user to select characters by moving the eyes (which are monitored by a computer with the help of a video camera). The system yields good results and working with it is relatively simple to learn, but its use causes a certain risk of strain.

Tecce et al. [17] present a character selection system based on EOG signals (which document the relative position of the eyeballs). The average performance reported there was about one character every 2.6 seconds.

Much better results yielded the eye-controlled device described in [18] (although it requires additional motor control over the eyelid). The system determines the line-of-sight of a subject by examining the reflection of his or her eye illuminated by a near-infrared light source and invokes commands when the subject generates an intentional blink. Since position and orientation of the head are also taken into account, the operation of the device is very stable. However, it requires a lot of special hardware.

Furthermore, an eye-controlled device is not suitable for e.g. a wheelchair control either, since the driver of a wheelchair has to watch the “traffic”, and is thus not free in using his or her eyes for control purposes.

3 System Architecture

The idea presented in this paper is related to the development of an input device that is both an aid for

people with disabilities *and* an easy-to-use, practicable tool that might be used for controlling a mobile robot or a moving wheelchair (eventually, this might even be an alternative to the standard input methods – at least concerning some specific applications – also for able-bodied people).

The goal is to devise a system that requires as little physical effort as possible, while being reliable, fast and practicable at the same time. It should have become clear from the discussion above that neither EEG nor EOG signals can serve as the basis for such a device. Instead, this paper will concentrate on signals related with muscle contractions, and it will be demonstrated that the control over a single muscle suffices to operate a corresponding application.

The basic architecture of a biosignal interface is illustrated in fig. 1. For instance, when talking about an EEG-based BCI, the *Data Acquisition* component refers to an EEG machine recording the brain-waves of the user (also called *subject*) and to the preparation of the EEG data for the analysis done by the *Signal Processing* component (probably involving a neural network classifier), while the *Target Application* might e.g. be a “spelling device”.

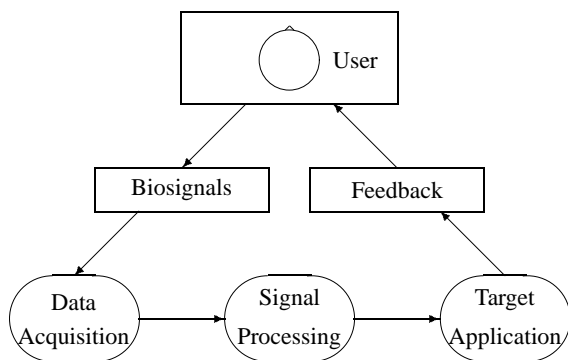


Figure 1: Basic Architecture

If one wants to develop an interface requiring as little physical effort as possible – making it suitable to be used by persons with severe disabilities – it might be tempting to think of an EEG-based BCI (since generating the necessary variations in the brain-waves causes the least *possible* physical effort – only involving *mental activities*).

Unfortunately, the resulting device would only work – i.e. produce acceptable results – if its user sat perfectly still in front of the computer.

The reason for this is that the EEG signal is extremely sensitive to noise caused by muscle contraction artifacts. Figure 2 shows an EEG trace that documents this sensitivity. The subject this trace originates from does nothing at the beginning of the recording.

After about 1.2 seconds, the subject is asked to slightly turn the head. This tiny movement results in a huge burst of activity with amplitudes of more than ten times as high as in the uncontaminated portion (note the rather coarse scale).

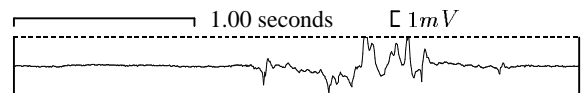


Figure 2: EEG Trace Contaminated by Muscle Contraction Artifact

The phenomenon of such movement-related bursts considerably disturbs EEG analysis, since the resulting signal has nothing to do with the user’s thoughts (as the EEG signal *usually* does). The problem becomes particularly obvious when looking at the frequency spectrum, which is often chosen for *representing* the EEG signal. As can be seen in fig. 3, the spectrum belonging to the contaminated signal contains numerous peaks at various locations.

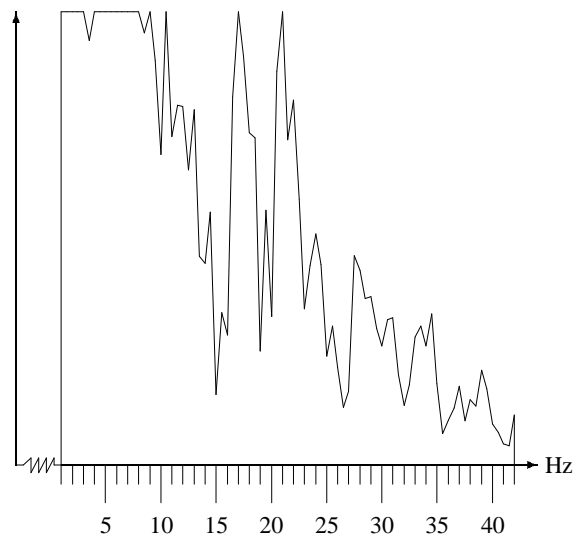


Figure 3: Frequency Spectrum of Contaminated Signal

Fig. 4 – showing the 10 Hz α -rhythm (which is dominant in the artifact-free EEG signal when

the eyes are closed) – clearly demonstrates why the contaminated signal is simply useless.

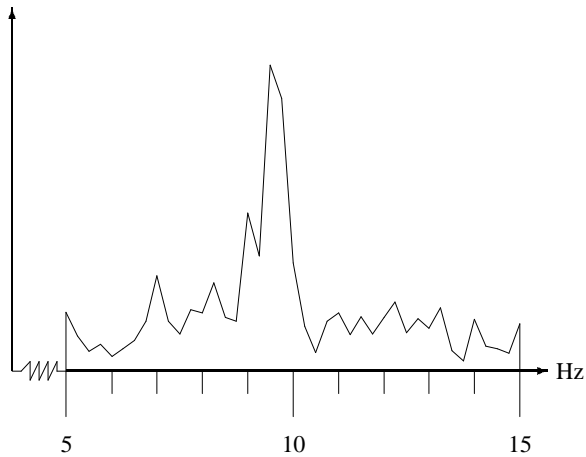


Figure 4: Frequency Spectrum Showing α -Rhythm

Therefore, in order to reliably employ an EEG-based system, its user would either have to be completely *unable* to produce any artifacts, or he or she would have to totally *renounce* any disturbing muscle contraction (which, by the way, also includes talking). Consequently, an EEG-based BCI does *not really* seem to be a perfectly practicable tool.

On the other hand, it is extremely simple to distinguish noise-free phases in the EEG from artifact-related phases, merely by looking at the “EEG curve”. Artifact detection can simply be done by inspecting the amplitude of the signal, since that is much lower in the artifact-free EEG.

This observation is the foundation of the idea introduced here. Instead of dealing with (genuine) brain-waves, the EEG signal is searched for (wilfully generated) muscle contraction artifacts. Alternatively, the *EMG* signal of the subject (recorded with a dedicated EMG machine) could be analyzed directly – since intentionally produced contractions are accompanied by similarly obvious amplitude changes in the EMG signal.

In order to facilitate the detection of muscle contractions, the user chooses one particular muscle he or she can activate reliably and fast, and an EEG (or EMG) electrode is placed directly above that muscle.

The analysis of the biosignal is done as follows. The output $s(t)$ of the primary acquisition device (i.e. the EEG- or EMG-machine) is fed into a computer, which observes the amplitude A of the sig-

nal and determines whether or not this amplitude exceeds a certain (user-specific) threshold T .

If the amplitude of the signal exceeds the threshold once as depicted in fig. 5a (which is similar to a single “mouse click”), the computer registers an e_1 event.

In addition, if a second e_1 event is registered directly after the first (with a time interval of less than t_0 in between), those two events are regarded as a new one (which is similar to a “double click”). This new event – denoted e_2 – may be seen in fig. 5b.

Actually, in order to make the system more intuitive for the user, an e_1 event is registered *at the onset* (the rising edge) of the event, and the rising edge shortly after an e_1 event is regarded as the onset of an e_2 event.

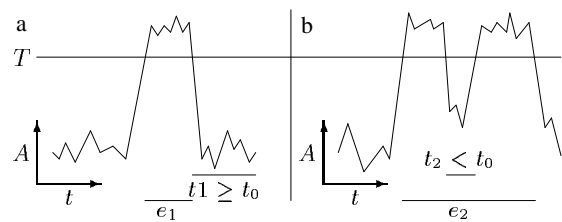


Figure 5: Detectable Events

The detection of these two events is all that is needed to communicate with the computer – involving the selection of one of a total of five “commands” (also called *states*).

For this, the input stream is analyzed (so that only a sequence of e_1 and e_2 events – interrupted by non-event phases – remains) and the *state diagram* that is depicted in fig. 6 decides on what to do if an event is generated by the user of the system (the names of the states are just defaults).

At the beginning, the system is in the “HALT” state, until an e_2 event occurs, after which the first “STRAIGHT” state is entered. By generating e_1 events, the user can then cycle through the “STRAIGHT”, “LEFT”, “STRAIGHT”, and “RIGHT” states, and he or she can return to “HALT” in any state just by generating another e_2 event.

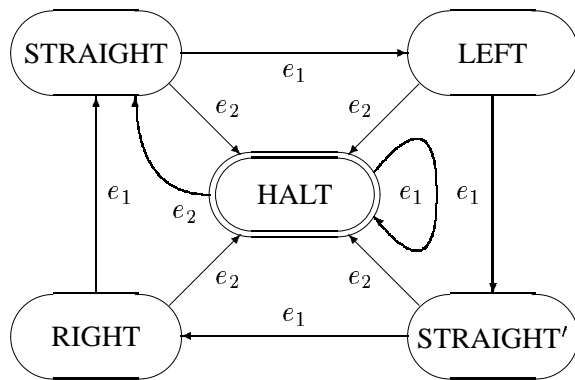


Figure 6: State Diagram

As a result, the current state can be used to control all sorts of output signals – it is e.g. possible to make the computer write characters, words and even entire letters if the input signal is processed in such a way. Consequently, a severely disabled person can write e-mails, i.e. have a “social life”, just by raising the eyebrow.

4 Possible Target Applications

An example application for an EMG-based interface has already been mentioned: a spelling device. As demonstrated in [19], it is possible to use the stream of contraction events as a substitution for the standard keyboard and mouse input devices. The input device illustrated there allows “typing” at a rate of about 4–5 characters per minute, while at the same time being almost insensitive to noise.

The tool might be combined with a word processor to yield even better results. Admittedly, the “typing rates” are *much* lower than what might be reached by an able-bodied person with a standard keyboard, so this particular application specifically addresses persons with disabilities.

Another example application – also representing an assistive device for disabled individuals – is given by a control system for an electrical wheelchair (see [20]).

Here, the default state names directly correspond to the respective movement directions of the wheelchair. The resulting system is easy to use and quickly adaptable to different users (or, in this case, wheelchair drivers).

Moreover, the discrete command/state output of the EMG control might be used by *able-bodied*

persons, e.g. for emulating the infrared remote control of the TV or the CD player, and a special headset would even allow operating a touch tone phone by “frowning”.

Finally, by building a menu-driven system around the EMG control output – probably employing a strategy similar to the spelling system mentioned above (which involves moving a virtual object on the computer screen) – it becomes possible to operate complex applications (e.g. to “surf” the internet by navigating in a web browser) with the help of simple muscle contractions.

5 Conclusions

The idea for an alternative interface has been described, which allows the interaction with a computer by controlling any muscle of one’s choice. Since the detection whether or not a muscle is contracted is almost unaffected by anything else but that muscle (e.g. any movement involving different muscles), the prospective device is very robust and practicable.

There is a wide range of possible target applications, some representing an aid assisting disabled people in using a computer, others constituting an alternative for everyone who wants to control something with the help of a computer.

Since a device relying on muscle contraction signals can be operated in an easy and effortless way, is almost independent of any undesired interference, and requires at most three electrodes (one for measuring, one reference, and the ground electrode), it is imaginable that even able-bodied subjects use the device in a number of applications.

Examples include a phone headset allowing to dial by “frowning” or an “eyebrow-operated” infrared remote control for the home entertainment center.

To summarize, there seems to be a huge number of possible uses of the idea presented here. Future tasks should deal with the identification of further possibilities, the realization of promising applications, and the testing of their usefulness.

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