FACIAL EMG SIGNAL ANALYSIS METHOD AND ITS IMPLEMENTATION AS A STAND-ALONE SYSTEM

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INTRODUCTION

This paper describes a stand-alone, second generation, low-cost facial muscle-activity S-EMG (surface-electromyography) binary switch that is designed to form the basis of communication and environmental control systems for those with severe physical challenges, arising from, for example, *amyotrophic lateral sclerosis (*ALS), Parkinson disease, muscular dystrophy and multiple sclerosis.

The original system employed a Fast Fourier Transform (FFT) algorithm to process signals and was successfully used to control devices such as nurse-call equipment and computers. The new design features wavelet processing and is significantly more robust and easier to use. It also has an LCD display (as opposed to LED indicators) that greatly reduces power consumption and allows menu-driven control of a variety of parameters, including variable gain. The built-in rechargeable battery, which lasts at least 40 hours between charges, makes the system completely portable and suitable for wheel-chair applications.

The new system consists of a low-cost headband (fabricated in-house), a connecting cable and a signal processor unit that samples and analyzes the *S-EMG* signals. The headband holds three *S-EMG* electrodes that generate a single channel of differential *S-EMG* data. The use of wavelets, compared to FFT processing greatly increases the system's ability to detect desired signals and reject artifacts and noise. We have undertaken a series of laboratory tests which demonstrate the system's capability of rejecting background noise and artifacts from eye-blinks and other involuntary facial movements, while at the same time reliably detecting eyebrow-raises and jaw clenches.

HUMAN INTERFACE ISSUES

Facial muscle EMG systems are designed to take advantage of the fact that for virtually all types of neurological and trauma disabilities, persons retain the ability to consciously control at least one facial muscle even after they have lost the conscious control over all muscles below the neck. Furthermore, some subjects are able to exercise some control (albeit sometimes with training) over their jaw muscles by clenching the teeth, and the forehead muscles by wrinkling the forehead, even after losing control of most of the facial muscles including the muscles which *move the eyes from side to side.*

Two additional groups of potential users for this system are users with spastic movements, and disabled users who retain some limited limb movement. In the case of spasticity, a variable gain capability is used to distinguish the much larger consciously generated signals from the involuntary movements. Our new unit can also be used by disabled persons who have the use of one or more limb muscles, thereby giving them the ability to rotate the forearm, or slightly raise a foot.

Our system has an improved human interface employing an automated threshold setting and calibration process. The previous system required some expertise to manually adjust the threshold value for signal detection. In addition, verification of proper headband adjustment is now made much easier by making reference to a simple numerical display during initial adjustments. Figure 1 is a photograph if the complete EMG system.

Figure 1: Photograph of the EMG Device

SYSTEM ARCHITECTURE

The EMG-switch has two main components - a headband and a signal processing unit. The headband holds three Ag/AgCl electrodes which are connected to differential amplifiers in the signal processing unit via a shielded cable. The electrodes are positioned so that they are in contact with an area that extends approximately 2 inches across the forehead. These electrodes monitor changes in electric field that come about through the contraction of muscles in or near that region.

The centre electrode is used as the ground and the other two electrodes are used as inputs to the differential amplifier inside the signal processing unit. Amplified signals are passed through hardware filters with a bandwidth of 350-700 Hz. The filtered signals are then digitized with a 10-bit analog-to-digital converter (ADC) at 2 kHz. The digital data is passed to a microcontroller for further processing. The micro-controller analyzes the digital data to reject background noise and artifacts, and detect the presence of S-EMG signals from eyebrow raises and jaw clenches. If a signal is detected, the relay-out circuit is closed. The user receives visual feedback from the LCD display. Figure 2 shows this data flow.

PROCESSING METHOD

To detect facial expressions, the time-domain digital S-EMG data are analyzed with wavelet signal processing techniques [1]. Data are arranged in buffers of 128 samples with an overlap of 64 samples. Each time-domain buffer is transformed to the wavelet-domain with a three-level wavelet tree as shown in Figure 3.

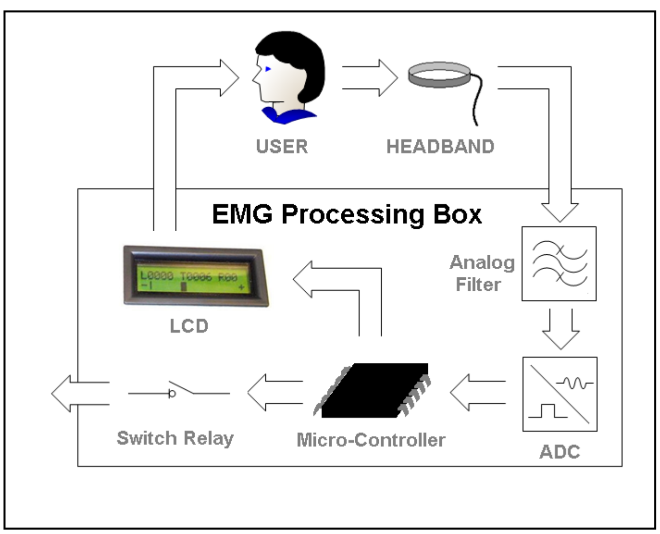

Figure 2: System Overview

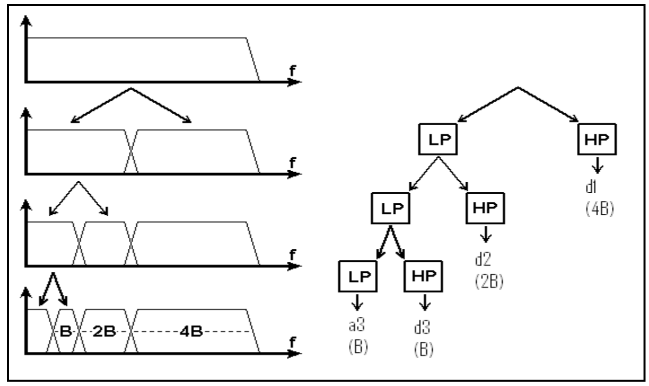

Figure 3: Three-level wavelet decomposition tree with warped decomposition in the frequency-domain

At each level, the signal is split into two signals of half its bandwidth and half its sampling frequency. The signal with the higher frequency content ends at the terminal node of that level, and the signal with the lower frequency content is subdivided further. Thus, frequency resolution is higher at lower frequencies and lower at higher frequencies. This leads to a warped disintegration of the time-domain signal in the frequency domain. Lower frequency resolution at higher frequencies reduces computational requirements and makes the processing more efficient. The root mean square (RMS) value of data from the four terminal nodes – d_1, d_2, d_3 and a_3 as shown in Figure 3, are used for analyzing the *S-EMG* signals.

The analysis method has two components – background noise estimation and signal detection by auto-thresholding. For background noise estimation, 2 seconds of *S-EMG* data are acquired with the user at rest, and arranged into buffers of 128 samples each. The buffers are wavelet-transformed and RMS values are computed for each terminal node of the tree for all buffers. For each terminal node, the maximum RMS value over all buffers is stored as an energy level threshold, creating a four-dimensional noise feature used as an individual threshold for each node.

For signal detection, a signal buffer is decomposed into its wavelet domain and RMS values are computed for the 4 terminal nodes of the wavelet tree. The RMS value for each bin is then compared to the thresholds set from background noise estimation. If the RMS value for a terminal node is greater than its threshold, then the threshold is subtracted from it. Conversely, if the RMS value for a terminal node is less than its threshold, its RMS value is set to zero. The sum of the resulting RMS values from all 4 terminal nodes is compared with a user-set threshold. If this sum exceeds the user-set threshold, the buffer is accepted as a signal of interest and the relay circuit is

Table 1: Typical wavelet node output values

Action	Wavelet Tree Terminal Nodes (typical RMS values in units of counts)			
	d_1	d_2	d_3	a_3
Resting	201	97	175	325
Jaw Clench	237	246	510	1005
Eyebrow Raise	315	253	530	838

closed. If this sum does not exceed the user-set threshold, the buffer is rejected as background noise or artifact. Typical node values are shown in Table 1.

SYSTEM TEST SET

In order to objectively assure the proper functioning of each unit produced, we have designed a test set that generates realistic EMG test signals based on data collected from forehead measurements. It should be recognized that the dominant noise source for our EMG system, as well as for any well-designed EMG system, is the noise generated by the skin-electrode connection, which we call the 'skin' noise in this paper. The design requirement for the EMG measurement device is that the noise contributed by the electronics must be small with respect to the skin noise. Furthermore, skin noise has a unique spectral distribution, with a very large low-frequency component as compared to the usual electronic white noise. It should be recognized that in field operation the fit of the headband (as well as the status of the headband itself) is normally and properly evaluated by measuring the level of the skin noise. In a poorly placed headband, the skin noise is much higher than normal.

In our new wavelet-based units, the acceptable skin noise level is displayed as a numerical quantity. Therefore, in order to perform a proper pass-fail test, digital sequences of EMG signals from actual skin noise and other physical actions such as eyebrow raises and jaw clenches were recorded with a properly fitted headband and amplifier. These recorded data were used to create constantly repeating sequences of noise plus one signal event per each sequence, where each sequence is about 60 seconds long. Five different sequences are used - one noise-only for a user at rest, two for noise plus minimum detectable signals, and two more at higher signal levels. These constantly repeating sequences are stored in a PC, and the digital versions of these are transmitted to the hardware test set, depending on which sequence has been selected by the test conductor.

The test set hardware consists of a digital-to-analog converter and filter, high level amplifiers to create the two balanced-signals emulating the output of a 3-electrode headband, and a precision passive two-channel attenuator to reduce the signal to the proper millivolt level without introducing extra noise. An EMG unit is first run with the noise-only mode to insure that the gains are at the correct levels, the processor is working, the proper noise level is registered on the display, and a zero false-detection probability is measured. The unit is then tested with the minimum-detectable-signal sequence to ensure 100% detection probability.

We believe this test set hardware and procedure achieves the highest quality of sensitivity testing for our EMG hardware unit, or for an EMG unit of any kind. Further, it allows the more difficult testing of a headband, by independently verifying that the EMG hardware is operating according to specifications. In that mode, the test set can be considered a head-band emulator, allowing comparison testing with the headband under test using a standard EMG processor unit.

SYSTEM USAGE

The headband is fastened around the user's head such that the three electrodes inside the headband sit on the user's forehead. The EMG skin noise display should read in the region 500 to 550. If it reads higher the headband must be re-adjusted until the skin noise is reduced. The most common error results from the headband being placed too high on the forehead. Ideally, it should be placed just above the eyebrows.

Once a proper electrode-skin connection has been made, the user is required to relax for 2 seconds so that background noise data can be collected. This recording is used to set thresholds for each node of the wavelet tree. If required, a longer recording time can be specified in the system settings. After this estimation of background noise features, the system is ready for use.

SYSTEM PERFORMANCE

The first generation system has been successfully used to help people with physical disabilities control devices such as nurse-call equipment, computers and other peripheral devices. Our new system offers the same functionality with greatly improved performance. We have carried out preliminary trials that have demonstrated the new system's capability to reject background noise, artifacts from eye-blinks, and other involuntary facial movements, while at the same time reliably detecting eyebrow-raises and jaw clenches.

We have fabricated 4 Beta test systems, and are in the first stages of organizing a three-month Beta test program under the umbrella of the University of Victoria Human Research Ethics Board. Our goal is to recruit and test 10 or more severely disabled persons, as well as 10 non-disabled persons as the control group.

We believe that our system can form the basis of very robust, reliable and low-cost communication and environmental control system for subjects with severe physical challenges, arising from, for example, ALS, Parkinson disease, muscular dystrophy and multiple sclerosis.

FUTURE WORK

We are confident that with further analysis it should be possible to extract more features from single-channel *S-EMG* data. This will allow the system to detect and categorize more than one source of facial muscle movement.

REFERENCES

[1] G. Strang and T. Nguyen, *Wavelets and Filter Banks*, Wellesley-Cambridge Press, 1997.