New Methods of Detecting Voluntary Blinking Used to Communicate with Disabled People

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***Abstract*—In this paper two new methods of detecting a voluntary blinking and neglecting involuntary blinks are comparatively presented. This technique is used to communicate with disabled people by using the EOG acquisition system. The proposed methods are based on Hilbert transform and envelope detection of the low frequency differential EOG signals. To safely detect voluntary blinking pulses, these methods use an adaptive threshold depending on the level of the low frequency EOG signal. The prototype of the proposed system has been designed, constructed and tested for different subjects from medical care centers, hospitals and treatment units. The experiments that we made with patients have confirmed the performing operation of the proposed EOG acquisition system.**

***Index Terms*—communication technology, eye tracking, electromyogram, EOG, neuromotor disability**

I. Introduction

Significant effort was made worldwide in the last years to implement communication techniques with severely neuromotor disabled people.

To communicate with disabled people, different technologies have been imposed along the years [1] – [30]. Among these, a special attention is paid to the *non-verbal communication technologies*, divided into two categories: by *gesture* or *gesture-assisted* [7].

One of the best performing computer-assisted non-verbal technology used to communicate with severe neuromotor disabled patients is the *key words* technology, widely described in [9] – [13].

By using this technique, on the patient's screen, key words accompanied by suggestive images and sounds are successively displayed. The patient needs can be detected by the press of a button (a simple switch) or by eye tracking techniques [9] – [11].

For the patients who can perform different voluntary movements and muscular contractions, adequate sensors are used in order to detect their muscles' contraction and to send their needs to the caretaker. According to the patient condition, different types of sensors can be used, acted by hand, foot, finger or by breathing (e.g. *Sip/Puff Switch*), commercially available from numerous manufacturers of medical equipment [14] – [15].

Patient needs detection by eye tracking techniques is used only by patients with severe neuromotor disabilities, who cannot perform any voluntary movements. These techniques can be implemented on the basis of electrooculography (EOG) and video analysis of the eye ball movement.

In the communication systems based on key words technology, the patient's needs, represented by the desired word, phrase and/or ideogram (selected by using an adequate switch or by one of the eye tracking techniques) are sent to the dispatcher or directly to the caretaker (using different wireless techniques) who ensures an adequate response [9] – [13].

For the patients with severe neuromotor diseases, who are completely immobilized and have no other possibility of communication with caretakers, their needs detection can be made only by eye tracking based techniques.

For these patients, eye tracking techniques consist in moving a cursor on the patient display according to eye balls movement. The selection of the desired key word or ideogram from the patient display is done based on voluntary blinking, ignoring involuntary blinks.

One of the major issues concerning the patients' needs detection with the EOG based techniques is represented by the difficulty to recognize the voluntary blinks from the involuntary ones, if a fixed threshold is used in EOG signals processing [9], [16]. Unfortunately, this method cannot be used when the EOG signals magnitude varies for different reasons in the communication process.

In this paper, two new methods for safe detection of the voluntary blinking pulses by using an adaptive threshold technique in the EOG signals processing are proposed. The rest of this paper is organized as follows. In Section II the communication principle based on eye tracking technique by using the electromyogram acquisition system is presented. In Section III the new methods for safe detection of the voluntary blinking pulses by using Hilbert transform and envelope detection of the low frequency differential EOG signals are proposed. Section IV describes the testing of the new communication procedure in medical care centers, hospitals and treatment units and the main types of diseases for which it was designed are presented. A few conclusions of this paper are presented in Section V.

II. Eye Tracking Principle Using the Electromyogram Technique

In the literature, different electromyogram based methods used to detect eye movements have been proposed [16] – [30]. EOG technique can be used as an assistive technology, such as HMI (Human Machine Interface) [17], which provides a pointing device that could be useful to people with physical disabilities, and for the determination of eye position in fast jet flight [18].

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In [19] Young reviewed major types of eye movement, and analyzed the advantages and disadvantages of various methods.

The electrooculogram is a biopotential signal recorded from the skin in the vicinity of the eyes. A standing electrical potential exists between the positively charged cornea and the negatively charged retina at the back of the eyeball [2].

Emil du Bois-Reymond (1848) observed that the cornea of the eye is electrically positive relative to the back of the eye. Thus the eye acts as a dipole in which the anterior pole is positive and the posterior pole is negative [20].

The corneoretinal potentials are well established and are in the range of (0.4 - 1.0) mV. Eye movements thus produce a moving (rotating) dipole source and, accordingly, signals that are a measure of the movement may be obtained. The chief application of the EOG technique is in the measurement of the eye balls movement [20].

In Fig. 1 the block diagram of the EOG acquisition system, consisting in both hardware and software components is illustrated [28].

The hardware component of this system consists in five electrodes (Fig. 2) placed around the ocular muscles, an improved EOG instrumentation amplifier and an A/D converter [28]. The signals provided by the hardware component are processed by the software component of the system, described in [29].

The hardware component of the EOG acquisition system is connected to the patient's PC (a desktop or a laptop) so that the screen is placed as close as possible to the patient, in different places, such as on the ceiling or on a wall [9].

The eye movement measurement involves placing pairs of electrodes either above and below the eye and to the left and right of the eye (Fig. 1). The combination of the differential signals provided by these electrodes is used in order to measure simultaneously horizontal and vertical movements of the eyes. If the eye is moved from the center position towards one electrode, this electrode "sees" the positive side of the retina and the opposite electrode "sees" the negative side of the retina. Consequently, a potential difference occurs between the electrodes. Assuming that the resting potential is constant, the recorded potential is a measure of the eye position [28].

The EOG signals vary by a few tens of microvolts per degree of eyeball rotation. Unfortunately, the underlying DC level varies over time [30]. To solve this problem, the instrumentation amplifier used in the proposed acquisition system (EOG amplifier in Fig. 1) provides coarse and fine DC level adjustment [28].

The differential signals $X_L - X_R$ and $Y_U - Y_D$ provided by the two electrodes pairs represent the horizontal and vertical eyes movements, respectively.

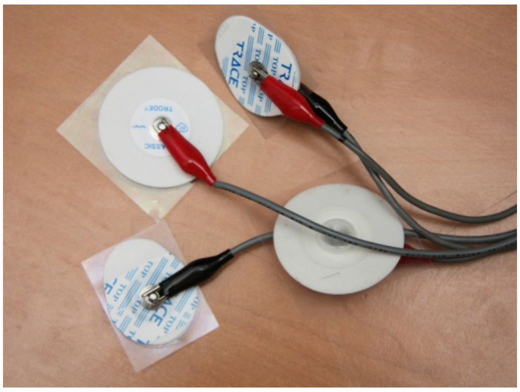

Fig. 2. Electrodes used by the acquisition system to capture the EOG signal

In order to perform the cursor movement on the patient display and to detect a voluntary blinking, these signals are processed by the software component of the proposed system, as it is shown in the block diagram in Fig. 1.

The signals $X_L - X_R$ and $Y_U - Y_D$ are low pass filtered, using a second order IIR filter with a cut-off frequency smaller than 0.5Hz. They are used to move the cursor (left – right and up – down) on the patient's display, as it is shown in [29]. Next, the same signals are processed in parallel in order to detect the voluntary blinks.

The main challenge of the EOG techniques is represented by the difficulty to safely detect a voluntary blinking and to neglect the involuntary blinks. To solve this problem, in the following, two new methods are proposed.

In order to use these techniques, the EOG signals provided by both channels have been captured from different subjects and experimentally processed, as it is shown in Section III.

During the experiments, the subject was seated facing the display PC's monitor, 50cm from the screen, and instructed to sit still and relax. The subject was instructed to track a single icon oscillating at various frequencies (0.2Hz, 0.4Hz, 0.8Hz and 1.6Hz) and with various amplitudes [30].

At each combination of frequency and amplitude, the steady state EOG signal was recorded. Some examples of data recorded during these experiments from both channels are shown in Section III.

III. New Methods to Detect a Voluntary Blinking

a) Hilbert transform

The Hilbert transform, because of its features described in the literature [32], is very useful in biologic signals processing.

It is known that Hilbert transform can be used to detect the envelope of a narrowband signal.

According to practical determinations, the EOG signal

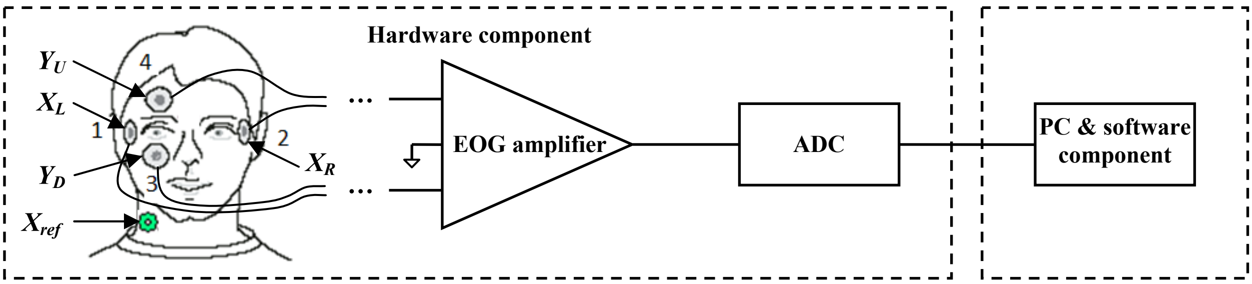

Fig. 1. Block diagram of the EOG acquisition system and electrodes position around the patient eyes

$\boldsymbol{x(t)}$, derived from a pair of electrodes, is a narrowband signal, having the frequency equal to test icon oscillation in 0.2Hz – 1.6Hz range; thus, it can be expressed as:

$$x(t) = X(t)\cos\Psi(t) = X(t)\cos\left[\omega_0 t + \Phi(t) + \phi_0\right] \qquad (1)$$

where $\omega_0 = 2\pi f_0$ is the mean value of frequency in the signal bandwidth and $\Phi(t)$ is the phase nonlinear variable component.

If $x(t)$ is a narrowband signal, then the curve $X(t)$ is tangent in the maximum points or very close to them and represents the *envelope* of the signal. This is described by the following equation:

$$X(t) = \sqrt{x^2(t) + x_1^2(t)}; \quad \Psi(t) = \arctan\frac{x_1(t)}{x(t)} \qquad (2)$$

where $x_1(t)$ is *harmonic conjugate function* (*Hilbert transform*) of signal $x(t)$. The signals $x_1(t)$ and $x(t)$ form a pair of Hilbert transforms (*harmonic conjugate functions*) and are given by:

$$x_1(t) = -\frac{1}{\pi}\int_{-\infty}^{\infty}\frac{x(\tau)}{\tau - t}\,d\tau; \quad x(t) = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{x_1(\tau)}{\tau - t}\,d\tau \qquad (3)$$

The differential signals provided by the EOG acquisition system are quite similar to the harmonic signals, on which are overlapping the short duration and high amplitude pulses given by voluntary blinking (Figs. 3.a and 4.a).

If the Hilbert transform is applied to an EOG signal, a signal following its envelope, emphasizing the rapid variations, corresponding to voluntary blinks, is obtained.

To exemplify the method, one can consider in the following two differential EOG signals (corresponding to both left – right and up – down channels) taken from a patient during the phase of system testing, with their amplitude variable in a dynamic range of 6dB and having a 120s duration (Figs. 3.a and 4.a). In order to avoid the detection of parasitic pulses, the differential EOG signals are first low-pass filtered (using a second order IIR filter with a cut-off frequency of 2Hz), so that the high amplitude pulses corresponding to voluntary blinking are not significantly attenuated, as show Figs. 3.b and 4.b.

If we apply the Hilbert transform to the low-pass filtered differential EOG signal, there results a signal which follows its envelope, emphasizing the pulses corresponding to voluntary blinking (Figs. 3.a and 4.a). Next, this signal is low-pass filtered (using a second order IIR filter with a cut-off frequency of 0.05Hz) and thus its rapid variations (all voluntary and involuntary blinks) will be totally eliminated. Thus results a DC signal depending on the level of the low frequency differential EOG signal, which can be used as a threshold for voluntary blinking detection, as shown in Figs. 3.b and 4.b. Thus, this detection threshold will follow the variations of the differential EOG signal level, which can occur in the capture process. By using an adaptive detection threshold, the errors in the voluntary blink detection process will be eliminated.

The pulses corresponding to voluntary blinking are detected by comparing the low-pass filtered differential EOG signal to the adaptive detection threshold, illustrated in Figs. 3.b and 4.b, corresponding to both channels.

In order to avoid the detection of the parasitic pulses (given, for example, by a more pronounced involuntary blinking), the comparison of the two signals in Figs. 3.b and 4.b is made by using an algorithm analog to a hysteresis comparator operation. Obviously, the hysteresis level has been experimentally obtained.

In Figs. 3.c and 4.c the pulses detected on both channels, without any error, corresponding to voluntary blinks are presented.

b) Envelope detection

This method is based on the software detection of the low-pass filtered differential EOG signals envelope, from which the pulses corresponding to voluntary blinking are eliminated.

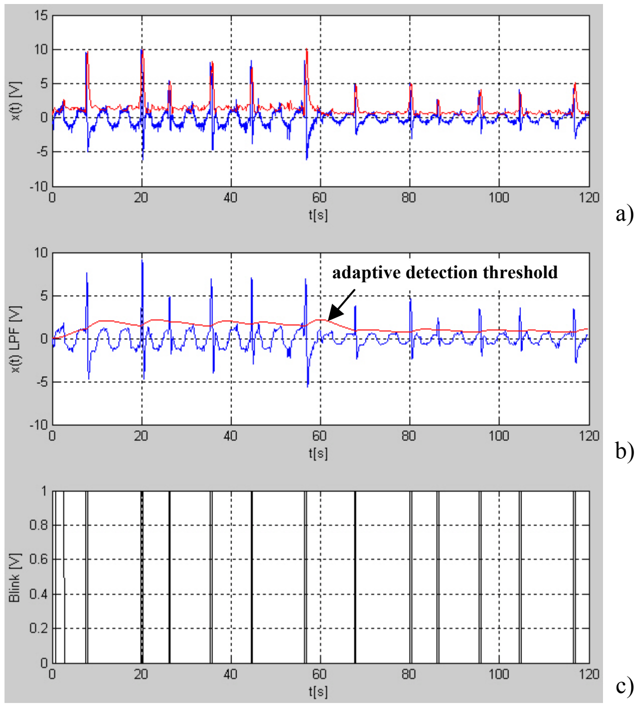

Fig. 3. Voluntary blinks detection by using Hilbert transform (left – right channel)

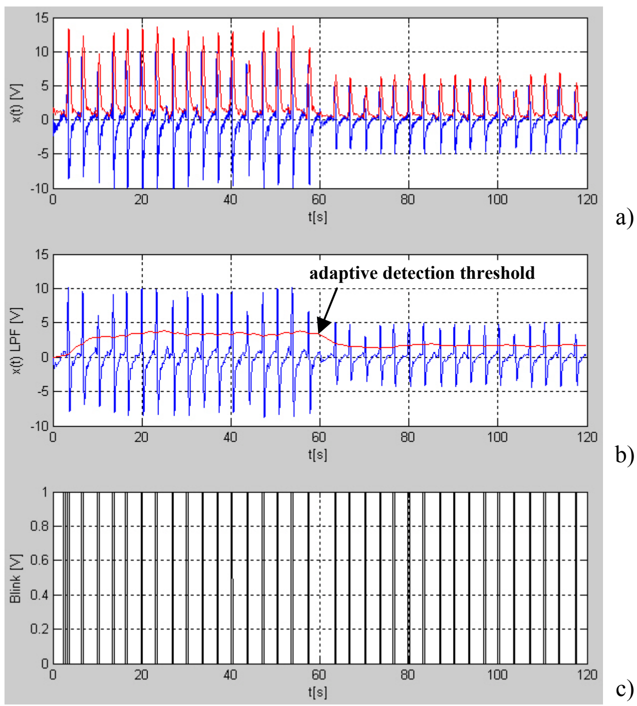

Fig. 4. Voluntary blinks detection by using Hilbert transform (up – down channel)

The integration slope of the envelope detector is chosen so that the pulses corresponding to voluntary blinking are integrated with a much lower slope than their own one, so that they can be detected and completely eliminated, subsequently.

In Fig. 5 the principle of this method is exemplified.

For a given value of the envelope detector integration slope (***S***), the value of the integrated signal in a time equal to the duration of a voluntary blinking pulse can be written:

$$\Delta V_{int} = S \cdot T_{blink} \quad (4)$$

where $S = \tan(\alpha)$ is the integration slope of the pulse (Fig. 5), and $T_{blink} \approx 0.37\mathrm{s}$ is the time duration of a pulse corresponding to a voluntary blink. For an integration slope of 60°, in the time equal to the sampling period of the differential EOG signal ($T_{sample} = 0.005\mathrm{s}$), the integrated signal value varies with $\Delta v_{step} = 8.66\mathrm{mV}$.

The integration slope of the envelope detector is chosen around the above value so that, on one hand, the high pulses corresponding to voluntary blinking are integrated and thus detected, and on the other hand, the lower pulses, correspondent to involuntary blinking are not integrated and not detected. So, the high pulses corresponding to voluntary blinking will be integrated and highly attenuated, but not totally eliminated. To eliminate completely the high frequency and high amplitude pulses, an algorithm was implemented, which compares the low-pass filtered differential EOG signal to the signal obtained by envelope detection. When the low-pass filtered differential EOG signal is higher than the signal obtained by envelope detection with an experimentally determined value (equal to hysteresis threshold), the pulse corresponding to voluntary blinking is completely eliminated. This procedure avoids the parasitic pulses detection.

To calculate the discharging constant of the envelope detector, one considers that it has an exponential type discharging, given by the following equation:

$$V_{o\min} = V_{o\max} \cdot e^{-t/\tau} \quad (5)$$

The discharging time constant τ derives from the condition that during the discharging period of the envelope detector ($T_{disch} \approx T_0$, where $T_0 = 3\mathrm{s}$ is the low frequency differential EOG signal period), the signal envelope should not decrease by more than 20% (Fig. 5):

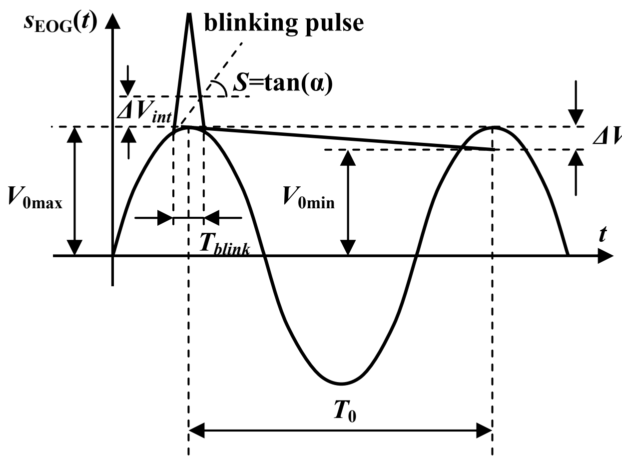

Fig. 5. Detail of EOG signal with a blinking pulse

$$\Delta v_0 = \frac{\Delta V_0}{V_{0\max}} = \frac{V_{0\max} - V_{0\min}}{V_{0\max}} \le 20\% \quad (6)$$

By replacing (5) in (6) there results the optimal discharging constant value: $\tau = 10\mathrm{s}$.

The signal resulted from this procedure (Figs. 6.b and 7.b) follows the low frequency differential EOG signal envelope (without the pulses corresponding to blinking) and is used as an adaptive detection threshold of voluntary blinking.

The pulses corresponding to voluntary blinking are detected by comparing the low-pass filtered differential EOG signal to the adaptive detection threshold provided by

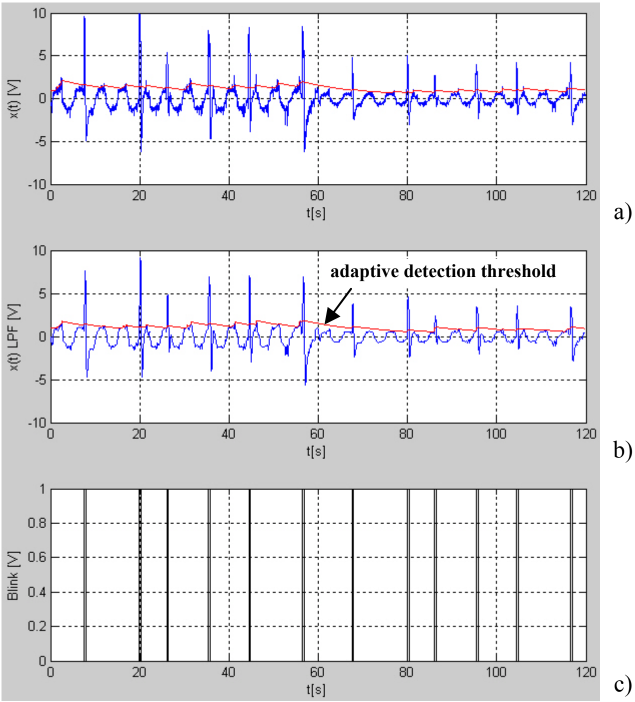

Fig. 6. Voluntary blinks detection by using envelope detection (left – right channel)

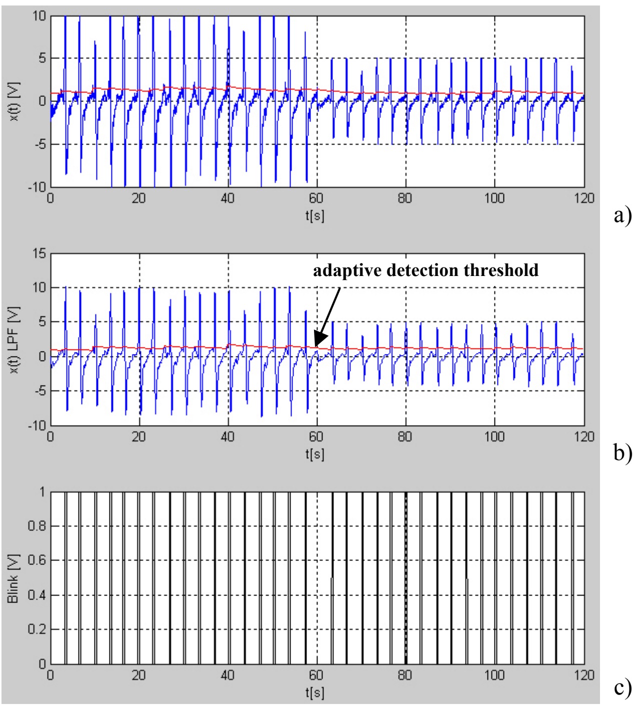

Fig. 7. Voluntary blinks detection by using envelope detection (up – down channel)

the envelope detection and eliminating the blinking pulses, illustrated in Figs. 6.b and 7.b, corresponding to both channels.

In Figs. 6.c and 7.c the pulses detected on both channels, without any error, corresponding to voluntary blinks are presented.

It is noticeable that, for both methods, the level of threshold follows the low frequency EOG signal envelope, which may vary during the same communication process or from patient to patient.

The major advantage of these two methods is represented by the new adaptive threshold technique, used for safe detection of the voluntary blinking pulses, independently of EOG signals magnitude variation, as it is shown in the examples illustrated in Figs. 3 - 4 and 6 - 7.

IV. Testing of the Proposed EOG-Based Communication Procedures

The proposed communication procedures based on EOG technique are dedicated to a special category of patients with severe neuromotor disability, hospitalized or not, who need continuous monitoring, covering the following types of patients:

- patients with a major neuromotor disability who are unable or have high difficulties in communication with other persons by usual modes: speaking, writing or by sign language, although they have an acceptable level of perception and comprehension, meaning hearing and/or seeing, understanding, but without signalizing;
- patients who can release inarticulate sounds and who can receive and understand simple acoustic or visual message (by loudspeaker and/or display), but cannot make any voluntary movement and who can signalize only through eye ball movement.

Thus, the proposed EOG acquisition system is dedicated to a complex number of patients with different physical and/or neuromotor diseases [33], such as: c*erebral vascular attack (CVA), cerebral motor infirmity, cerebral palsy (CP), troubles associated to CP, sensorial deficiencies, language disorders, non-cerebral motor disabilities* and many others.

The testing of the proposed system with EOG module in medical care centers was made in different phases, at different complexity levels, depending on the condition, cooperation and comprehension level of the patients.

Considering the complexity of the neuromotor diseases, during the tests there were used different “key words” databases with different complexity levels, adaptable according to patient needs. These were used both for the communication with the patients in order to find their basic needs, and for medical investigation.

The first tests with the patients were made by using the ASISTSYS system, implemented on the base of key words technology, illustrated in [9]. The patient component of this system includes an EOG acquisition module, having the software component implemented on the base of fixed threshold technique, used in EOG signal processing. The tests have confirmed the necessity of an adaptive threshold technique, due to modifying of the EOG signals magnitude depending on patient condition and for other different reasons in the communication process (position of the patient in front of the screen, the electrodes conditions and the patient’s level of fatigue, cooperation and understanding).

Before the testing, the subjects were instructed to use the communication procedure and to blink as distinctively as possible.

During the tests, the browsing of the key words database (organized on several hierarchic levels) is done by detecting the eye ball movements with the EOG acquisition module. The patient’s gaze follows several areas of the display where are placed the key words and/or the ideograms corresponding to his needs. The selection is made by a prolonged blinking, detected by the system’s software component, implemented by using the two new methods proposed in Section III. The selected requirement of the patient is transmitted wireless to the caretaker and the lower hierarchical level of the database is displayed on the patient’s screen.

All the patients who tested the proposed communication system could easily communicate with their family, caretakers and doctors, for medical investigation, on the base of this technology, thus system functionality being proved.

We can conclude that all patients’ feedback was positive, some of them even made suggestions for the improvement of the system performances. For example, some patients proposed the updating of the system for a complex use of a PC, having the possibility to access the Internet and personal e-mail.

The suggestions received from the patients during the system tests will be used to continue the research in this field of interest, in order to implement more complex communication systems, which could fulfill better the needs of these people.

V. Conclusion

In this paper a new communication procedure used to communicate with disabled people by using the EOG acquisition system has been presented. The system has been designed for the use of patients with severe neuromotor disabilities (unable to perform any voluntary movements) and uses the computer-assisted key words technology to detect their needs.

In the paper two new methods based on adaptive threshold technique in EOG signals processing, used to safely detect voluntary blinking and to neglect involuntary blinks have been proposed.

The prototype of the proposed communication system with EOG module has been designed, constructed and tested for different subjects from medical care centers, hospitals and treatment units.

The tests done with patients have confirmed a positive impact of the proposed solution for communication with disabled people.

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