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RESEARCH ARTICLE

A novel EOG-based wireless rapid communication device for people with motor neuron diseases

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ABSTRACT
In this study, a new electrooculography (EOG) based system that provides efficient communication for people suffered from motor neuron diseases is presented. The system consists of two distinct devices. The first device operates as a main unit that is activated by the subject's eye movements. This unit is capable of transmitting 10 different command/state messages. These messages enable subject to choose his/her situation such as "I'm fine", "I feel bad", "I'm hungry" and "I'm thirsty". Commands such as "Come", "Go". The number of messages can be increased. The main unit acquires the EOG signal from the subject. Newly developed analogue and digital signal conditioning interprets the eye movements as specific messages and transmits them to the second unit (receiver) using radio frequency transmitter. The messages related to the subject's demands and situation can be heard from both main and receiver unit speakers. The wireless receiver unit is capable of notifying the patient's command by auditory and visual indicators. The realised device was tested by 2 healthy and 2 ALS patients and confirmed to be successful with 100% performance for sending correct messages.

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1. Introduction

In recent years, studies on Human-Computer Interface (HCI) devices took great interest by the researchers. The importance of such devices becomes larger when designed to aid patients that lose their movement abilities due to motor neuron diseases (MNDs). Since speech ability is also impaired in such diseases, only restricted muscular signals even only brain signals become available for interpretation.

As an example for MND, amyotrophic lateral sclerosis (ALS) (or "Lou Gehrig's Disease") is a progressive neurodegenerative disease. ALS is the most common MND and it affects both upper and lower motor neurons. In other words, it affects the brain and the spinal cord nerve cells. Motor neurons reach from the brain to the spinal cord and from the spinal cord to the muscles throughout the body through different paths. The progressive degeneration of the motor neurons in ALS eventually causes to their death. When the motor neurons die, the ability of the brain to initiate and control muscle movement is lost. Even breathing, for example, cannot be possible without any supporting device. With voluntary muscle action progressively affected, patients in the later stages of the disease may become totally paralysed. ALS is usually fatal within 2–5 years of diagnosis. For the present, unfortunately, there is no known cure for ALS.

In addition to physical movements, many cognitive responses can be achieved by eye movements. The required time and energy cost for a physical (hand, foot, etc.) movement and its interpretation after imagination in the brain are much higher than eye movements accompanying and/or guiding to the physical movement.

Such states can be seen in ALS patients that have no ability of physical movement response to received information from their environment. In later stages of the disease, patients lose their ability to use whole of the muscles responsible for voluntary movement. However, eyelid, muscles around the eye that enables movement of the eyeballs are the muscles that become impaired in later stages of the disease, which makes electrooculogram (EOG) more suitable as a long-term sustainable communication modality for the ALS patients.

Electrooculography is a technique for measuring the resting potential of the eye. EOG results from eye

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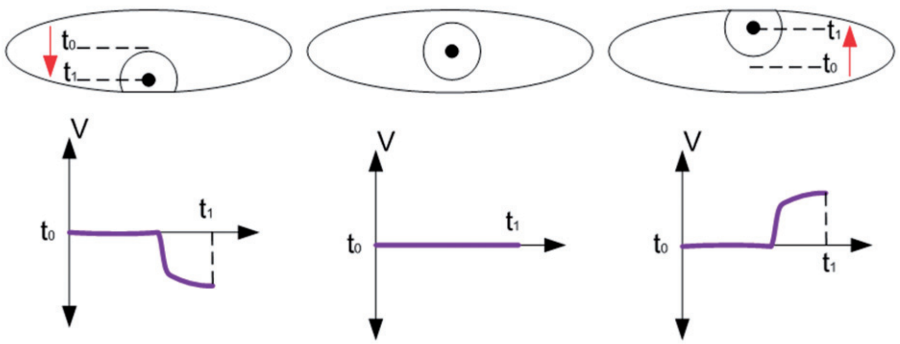

Figure 1. Electrooculogram signals due to eye movements.

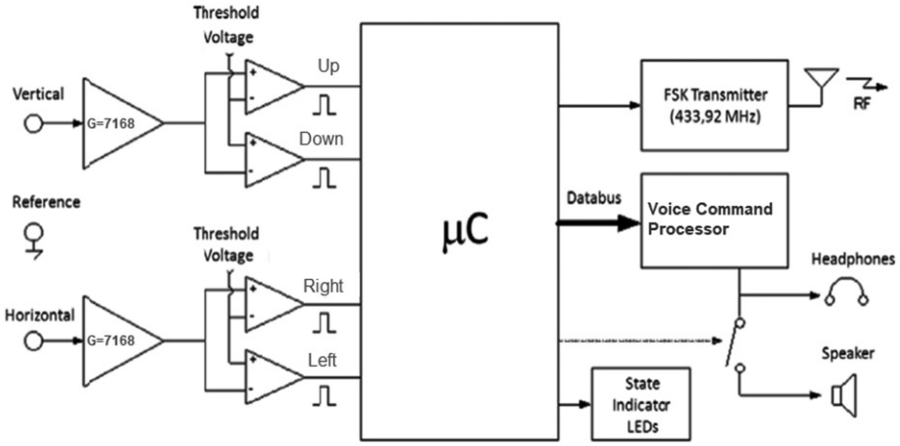

Figure 2. Block diagram of the main unit.

movements, and it is a corneal-retina potential due to hyperpolarisation and depolarisation (Figure 1). This potential can be modelled as a dipole and can be measured with bio-potential measurement systems. Eye movement directions and eye-blink signals can be measured and classified almost real-time with efficient and fast algorithms [1,2].

There exist several EOG based HCI applications designed for several purposes. Bulling et al. [3] designed wearable EOG goggles with dry electrodes and a small pocket-worn component with a digital signal processor (DSP) for real-time EOG signal processing. Later, they used the device for recognition of context-awareness in reading activity [4]. Hori et al. [5] proposed a control system based on eye-movements and eye- blinks. By using two EOG electrodes, four directional cursor movements (up, down, right and left) and one selected operation was realised by logically combining the two detected channel signals based on threshold settings specific to the individual. For control of computer functions with eye movements, Borghetti et al. [6] designed EOG acquisition and software included system by which the patients were able to move a cursor over a visual keyboard, selecting one letter to another by single ocular movements (left, right, up, down) and double eye-blink to select the desired letter. In addition to eye-movements, Kim et al. [7] proposed the use of voluntary sequential (double/triple) eye-blink to control a mobile robot for target tracking and point stabilisation.

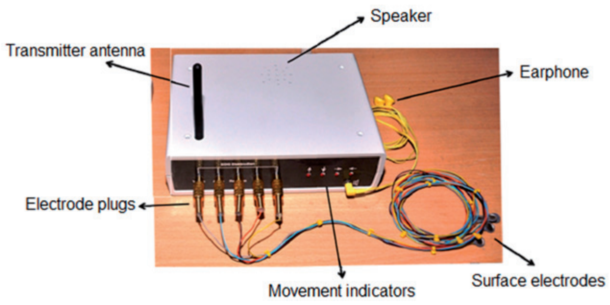

Figure 3. The main unit.

In addition to EOG signals, electroencephalogram (EEG) signals can also be integrated into HCI or Brain Computer Interface (BCI) systems. Such systems directly use brain generated (movement) signals which might make them the longest sustainable communication modality for simple device control [8–10] but they suffer from the need for complex interpretation of patient-specific cognitive responses that are

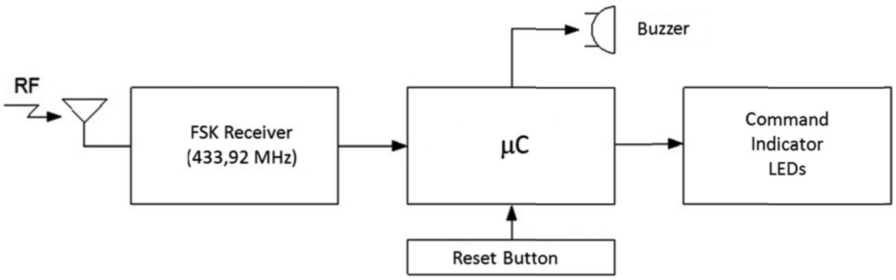

Figure 4. The block diagram of the receiver unit.

reflected to noisy and low amplitude EEG signal. Because of the pitfalls of the EEG based systems, EOG based systems are more practical and having high performance for the patients not completely paralysed [11,12].

Today, by qualified medical care - respiratory and food aids, many ALS patients are able to extend their lives to more than 5 years [13]. The main motivation of this study is to suppress the uncomfortable effect of the disease and increase the comfort, quality of life and life duration of ALS patients by using easily detectable EOG signals.

The aim of this study is to develop more practical, comfortable, robust and cost-effective system. The proposed system serves this purpose. Instead of using the complex algorithm based system, we pursue an embedded system on account of realising low-cost system with high performance.

2. The system

2.1. Main unit

The main unit (Figure 2) interprets eye-movements by two high gain instrumentation amplifiers and comparators of which threshold can be adjusted manually. The horizontal and vertical EOG signals (H-EOG, V-EOG), each having 2 electrodes, are first applied to amplifiers with a gain of A = 7168 (77 dB). The design rationale for a similar EOG based systems were realized and described in detail [2,12]. Each of the amplified EOG signals is compared by two different levels of threshold voltages, meaning two different comparators. The amplified V-EOG voltage threshold yields the existence of up- down eye movements whereas, for H-EOG signal, it yields right-left eye-movements, respectively.

Comparators (up, down, right, left) are designed in a way that they generate a high voltage (5V) if the corresponding eye-movement occurs (i.e. if left eye-movement occurs, the LEFT comparator generates "high" at the output.). These occurrences are also indicated by four LEDs, each corresponding to up, down.

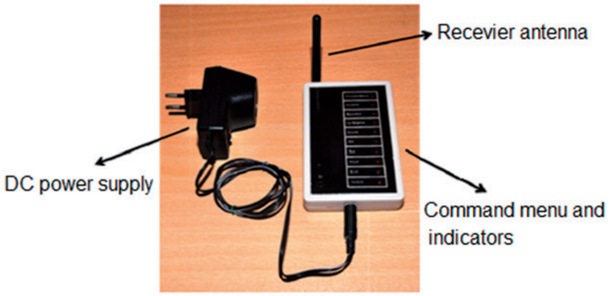

Figure 5. The receiver unit.

Table 1. Command menu.

Order	Message
1	Help me
2	Yes
3	No
4	Come here
5	Go
6	I am OK
7	I feel sick
8	I am thirsty
9	I am hungry
10	Move me

The comparator outputs (having a value of 0 V or 5 V TTL compatible voltage) are directly applied to (digital) input terminals of the microcontroller (PIC16F876). Microcontroller, then, interprets the existence of eye-movements referring to the developed algorithm and enables the selection of commands.

The main unit also involves the memory circuitry that stores pre-recorded sound data of the menu items. The sound data is used to generate an audio output to outer headphones or to the speaker which is also installed in the main unit.

After the selection, the menu item is transmitted to the receiver unit by a 433.92 MHz frequency shift keying (FSK) modulator. The communication signal is in the industrial, scientific and medical (ISM) band. The output of FSK modulator is fed to a quarter-wavelength transmitter antenna.

The mobile main unit has two 9 V rechargeable batteries and can be used anywhere without an external power supply. The recharging unit is also involved in

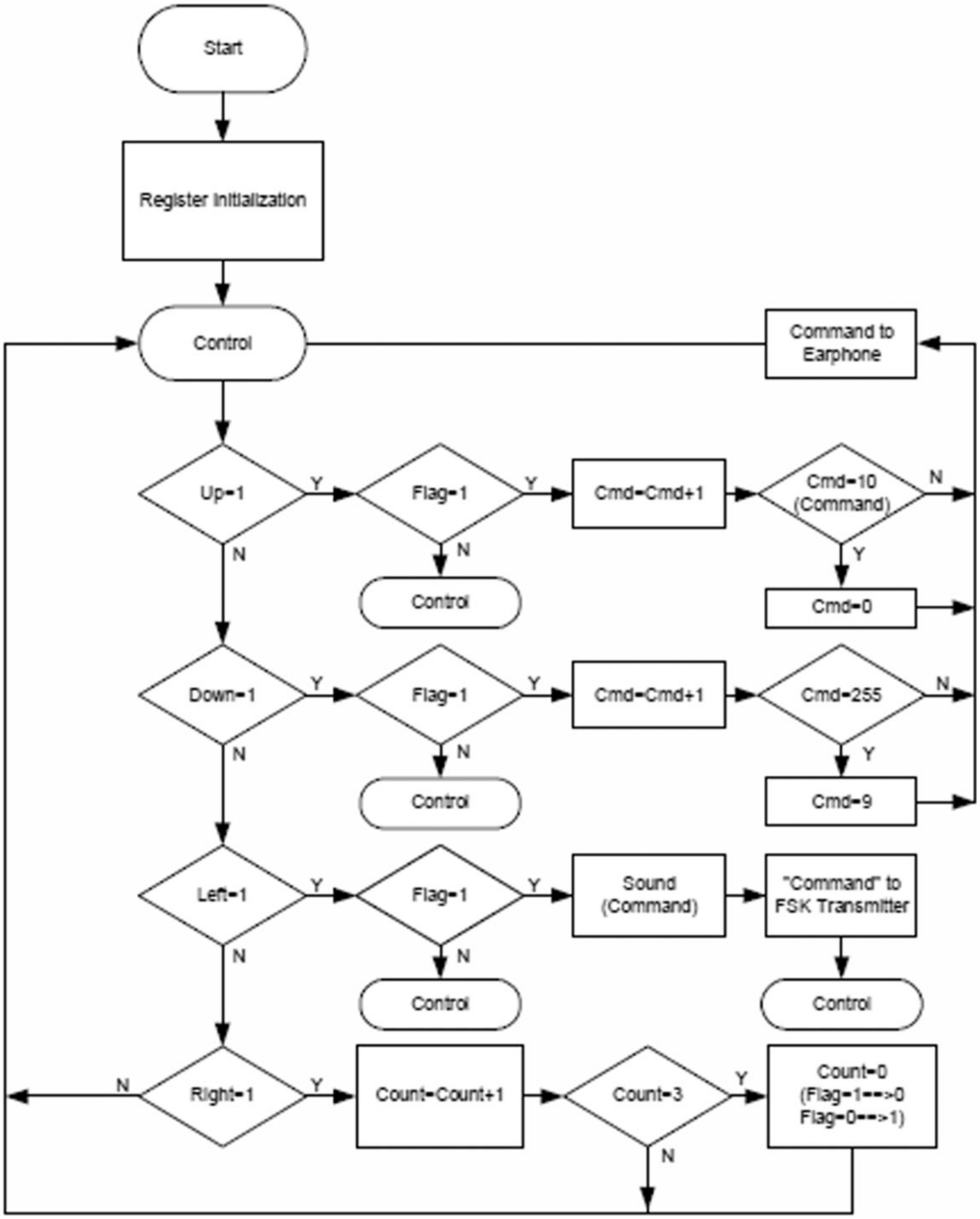

Figure 6. Eye movement interpretation algorithm.

the main unit which requires an external 12 V DC power supply. The main unit is shown in Figure 3.

2.2. Receiver unit

The microcontroller based receiver unit consists of a FSK demodulator, 10 LEDs, a reset button and a buzzer. After demodulation of high-frequency carrier signal, the message sent by the main unit is interpreted by microcontroller and the corresponding LED is on. The receiver unit can operate through 50–60 m distance from the main unit. The block diagram of the receiver unit is shown in Figure 4 and its outer view is shown in Figure 5.

2.3. Calibration

EOG signals can be observed in 0–100 Hz frequency band and of 100 mV; however, amplitude of the signal may be lesser with respect to the stage of the ALS disease. In order to determine eye ball position, voltage threshold should be set according to the user. For this purpose;

1. Channel UP threshold adjustment trimmer resistor is set to 0 V.
2. User needs to move his/her eye-ball to up with 5-second intervals.
3. Threshold trimmer resistor is adjusted until UP channel output rises to logic high (5 volts).
4. Five minutes relaxing time after, user is wanted to looking at up 25 times within 10 second intervals. If the logic high signal is observed 25 times, threshold adjustment trimmer resistor is fixed.
5. (i)–(iv) are repeated for down, right and left channels.

2.4. Control of the main unit and message selection

After the attachment of EOG electrodes and the main unit is switched ON, the user/patient should wait for about 10 s. This interval is required for the instrumentation amplifiers to settle down and have a zero DC offset at the outputs. By directional eye-movements and inspection of four LEDs, the state of the device can be determined, whether it is ready for operation or not.

The exact initiation of device operation can be achieved by triple “left to center” eye- movement. Following these eye-movements, the device starts to consume higher energy from the battery; that is, the “standby” mode ends. The patient can put the device back to stand-by mode anytime by repeating triple “left to center” eye-movement. After the device operation is initiated by the patient, the main unit waits for patient’s vertical eye-movement, i.e. Up, down or simply a blink. If any of these movements occur, the first command (Table 1) can be heard from the speaker (and the earphone if connected) located on the main unit.

After the auditory output, the patient may skip to the next message by simply repeating the same vertical eye movement or select the current message. The selection of the current message is achieved by a single “right to center” eye-movement. After the selection, the microcontroller sends the message to FSK modulator and the corresponding LED is immediately illuminated on the receiver unit. The caregiver, then, can easily recognise the message from the patient by simply looking at the illuminated LED. The caregiver should press the “RESET” button to enable the patient to select another message. If this button is not pressed within 5 min, the receiver unit starts to generate a buzzer train to attract the caregiver’s attention to recognise the message. Eye movement interpretation algorithm is shown in Figure 6.

Figure 7. Test stage (A.K.) [12].

3. Results and conclusion

Patients suffered from MNDs such as ALS, have muscular movement problems. Because they have lost overt speaking ability, they need more efficient and practical communication channels. Eye movement manipulated EOG based keyboard which was offered before [2] can be used for giving unlimited messages. But that system needs the user effort with eye movement to select a letter to write messages. The newly developed system is offered more practical wireless communication with fixed 10 messages (Table 1).

The realised device was tested on two healthy (both are male, ages 29, 41) and two male ALS patients. One of them is 51 years-old and an ophthalmologist (Figure 7), he is also one of the authors of this paper, and the other patient is 64 years-old and an otolaryngologist. At first, the electrodes were attached with paste properly. Secondly, they have tried to send 5 different messages. The experiment was repeated in two sessions within 10 min almost under same environmental conditions. Sending correct message performances were 100% for all sessions. The device operation lasted 6 h without any problem. The tests revealed that the device was successful to deliver patients' messages. However, for more than 6 h usage, drying electrode paste and the head movement seemed to degrade the performance of the device since this introduces artifacts by movement of the surface EOG electrodes. The artifacts cause unwanted menu sliding. For avoiding this problem, using sequentially intentional eye blinks to reach wanted message, is simple enough.

In this study, a simple in use mobile, rapid, practical and cheap (200 USD) communication device for MND patients is designed and realised. The device testing was achieved on ALS patients and found to be successful for daily usage. Since the wireless receiver unit can operate in a range of 50–60 metres, the system eliminates the need for the caregiver to be in sight of the patient. Our future studies will focus on improvement of electrode attachment methods on the skin and thus, increasing the usage comfort and success of the device.

Disclosure statement

No potential conflict of interest was reported by the authors.

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