International Journal of Bioelectromagnetism
Vol. 13, No. 4, pp. 195-200, 2011

Device for Recording the EEG in Emergency Neurology using existing ECG Infrastructure

Andrei D. Jakab[a], Pasi K. Kauppinen[a], Jari A. Hyttinen[a], Tapani Salmi[b]
[a]*Dept. of Biomedical Engineering, Tampere University of Technology, Tampere, FINLAND*
[b]*Department of Clinical Neurophysiology, Helsinki University Hospital, Helsinki, FINLAND*
Correspondence: A. D. Jakab, PL 692, 33101 Tampere, FINLAND
E-mail: andrei.jakab@tut.fi, phone +358 40 849 0989

Abstract. Prior work has demonstrated that the information contained in the electroencephalogram (EEG) is valuable in several emergency neurological conditions. However, due to the shortcomings of conventional recorders and the lack of guidelines regarding its use in emergencies, the EEG has remained underused in emergency medicine. In this paper, a novel, one channel device is described, which makes it possible to display and record a patient's EEG with electrocardiographic (ECG) monitors and recorders. Since it was especially designed for use in emergencies, the adapter is small, portable, and easy-to-use. Preliminary results indicate that under laboratory conditions the quality of the acquired signal is comparable to that of a commercial Neuroscan system. This research is a pioneering work in the field of EEG and emergency medicine since the recording situation that is envisaged differs greatly from conventional EEG recordings done in hospitals.

Keywords: EEG, emergency medicine, portable, easy-to-use, ECG monitor

1. Introduction

Even though modern neuroimaging techniques have reduced the clinical indications associated with it [Praline et al., 2007], due to its relatively low cost, short examination time, lack of risk and personnel requirements [Borges et al., 2010], the electroencephalogram (EEG) continues to be one of the most commonly used tests for the clinical evaluation of neurologic disorders [Markand, 2003]. It can help a physician distinguish among different types of unconsciousness and it is unmatched as a diagnostic tool for the detection of nonconvulsive status epilepticus (NCSE), which is a life-threatening situation that is under-diagnosed due to its subtle symptoms [Bautista et al., 2007]. The EEG has also been applied to the investigation of strokes, head trauma, and intracranial haemorrhages [Hooshmand and Maloney, 1980; Tatum, 2001; Farnarier, 1998].

Despite the existence of abundant literature that discusses the indications and usefulness for the application of EEG in the emergency department [Hooshmand and Maloney, 1980; Praline et al., 2004; Kothare et al., 2006; Alexan et al., 2001; Benbadis, 2008; Thomas, 1997], this diagnostic method remains underused in this setting [Bautista et al., 2007]. Moreover, in order to obtain a quality recording, an experienced nurse must apply the measurement electrodes, a process that can take up to one hour. Once the signals are recorded, only a trained neurophysiologist can interpret the data, as an unprocessed EEG is unintelligible to the untrained eye. These reasons together with the lack of standards regarding how and when the EEG should be employed in emergency situations restrict the use of this valuable tool. Furthermore, many small emergency centers do not possess any type of EEG recording capabilities since the required investment in infrastructure and training is deemed to be unjustified. This situation is in stark contrast to the electrocardiogram (ECG). Nowadays, ECG monitors can be found in medical centers large and small as well as in ambulances. Moreover, the signal can be easily interpreted not only by doctors but also by nurses and emergency medical technicians (EMTs). A comparison between ECG and EEG signals is presented in Table 1.

Our group has developed a one channel EEG-to-ECG adapter that allows a person's EEG to be recorded using the same infrastructure that is currently used for the recording of the ECG. During the validation process, the quality of the recorded signal was found to be comparable to that of a commercial Neuroscan system.

Table 1. *Comparison between the ECG and EEG signals.*

	ECG	*EEG*
Bandwidth (Hz)	0.5 – 100	0.5 – 80
Amplitude	Up to 5 mV	10 – 100 µV
Equipment Price	Cheap	Expensive
Availability	Widely in EM	Only EEG laboratories
Infrastructure	Exists in all hospitals and ambulances	Only in special units

2. Material and Methods

Figure 1 depicts the developed EEG-to-ECG adapter. The input (left side) and output connectors (top) of the 1-channel system as well as the light guide of the red-green-blue (RGB) light emitting diode (LED) and the area where the capacitive start/stop key is located are clearly visible. The green input connector is for the bias electrode, which is typically located in the Fpz location, while the two white connectors represent the input channel. They are connected to two electrodes also located on the forehead, usually in the Fp1 and Fp2 locations. The three limb leads cables of an ECG monitor connect to the output connectors on top of the adapter's enclosure. Since the EEG signal is outputted by the rightmost connector and is referenced to the remaining two, only one limb lead has to be displayed on the monitor in order to be able to visualize the patient's EEG. The adapter measures 80 x 60 x 30 mm and weighs only 87 g, including the battery.

Figure 1. *The EEG-to-ECG adapter compared to a standard 9 V battery.*

2.1. Measurement Electronics

As it can be seen in the block diagram shown in **Figure 2**, the adapter is actually a battery-powered embedded system that consists mainly of a one-channel, variable-gain EEG bioamplifier and an ATmega1284P microcontroller (MCU). The MCU samples the EEG signal in order to determine the appropriate gain in real-time. After every gain change, the EEG recording is temporarily interrupted and a sinusoidal scale-indicator signal with an amplitude equivalent to 100 µV at the current gain level is outputted by a pulse-width modulation (PWM) digital-to-analog converter (DAC). An on-board three dimensional accelerometer is used to determine whether the adapter is moving excessively. The user interface is made up of a red, green and blue (RGB) light-emitting diode (LED) unit and a capacitive button that starts/stops the recording.

A 380 mAh rechargeable lithium polymer (LiPo) battery powers the adapter. The battery can be recharged simply by connecting the adapter to a powered Universal Serial Bus (USB) port through the onboard mini-AB USB socket.

2.2. Adapter Operation

Upon being powered up, the adapter performs a number of initialization steps and then enters a standby state in order to conserve battery power. If the user touches the start/stop key, the adapter will exit the standby state and start analyzing the EEG signal.

The digitized EEG signal is analyzed by a software module that determines whether the gain of the adapter needs to be increased or decreased according to the following algorithm. The data samples are grouped into 1 sec windows and the maximum peak-to-peak (PP) amplitude over each window is calculated. If the calculated value is inferior to the lower threshold associated with the current adapter

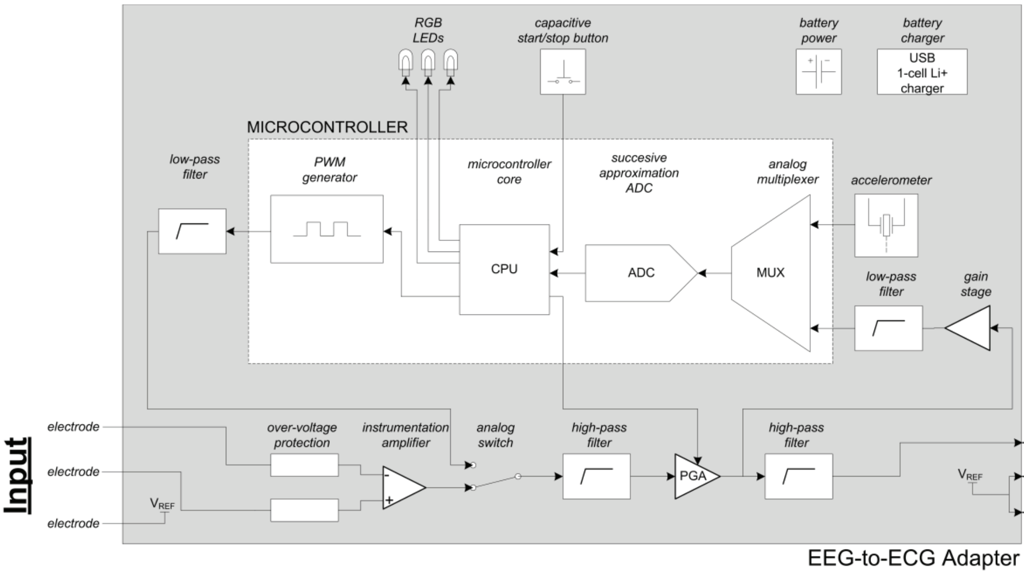


Figure 2. *Block diagram of the 1-channel system.*

gain, the gain level is increased by one step. On the other hand, in order for the gain to be decreased, the maximum PP amplitude must exceed the upper threshold for two consecutive windows.

Every 2 min, the adapter ceases to output the patient's EEG for 5 sec. During this time period, the PWM DAC outputs a sinusoidal scale-indicator signal with a frequency of approximately 15 Hz and an amplitude equivalent to a 100 μV input signal at the present gain step.

2.3. Evaluation of the System

Electrical Tests

In order to validate its performance, the adapter's operating time, standby time, and frequency response were measured. Also its signal to noise ratio (SNR) was compared to that of a commercial Neuroscan system in the following manner. Five-minute recordings were performed first with the Neuroscan and then with the adapter's output connected to the Neuroscan while a 100 μV, 5 Hz sinusoidal waveform generated by an Oxford XC-90III calibrator was being inputted. The 5 Hz input signal was defined as the desired signal while the remaining signal after the desired signal's removal from the recording with a narrow bandpass filter was considered as the noise signal. It was assumed that the amount of noise added by the systems, which overlaps with the desired signal's bandwidth, is insignificant compared to the desired signal's power and thus can be ignored. Since the noise signal from the 1-channel system's dataset was made up of components from the Neuroscan and from the adapter, the RMS noise level computed from the Neuroscan dataset was subtracted after being scaled appropriately from the adapter's RMS noise level. Finally, the SNR was computed by means of the following formula:

$$SNR = 20\log_{10}\left(\frac{A_{signal}}{A_{noise}}\right) \tag{1}$$

where SNR = signal to noise ratio [dB], A_{signal} = RMS amplitude of the desired signal [μV], and A_{noise} = RMS amplitude of the noise [μV].

Comparison with Commercial Neuroscan System

The signal quality was also evaluated qualitatively by measuring the spontaneous EEG of a 25 year old healthy female volunteer simultaneously with the Neuroscan system and the adapter. As described previously, the Fp1, Fpz, and Fp2 locations were employed. The signals were digitized at a sampling rate of 500 Hz with 16 bit resolution and were filtered by means of a band-pass filter with a bandwidth ranging from 0.184 to 100 Hz.

3. Results

Based on the data included in Table 2, it can be concluded that the adapter's electrical characteristics are comparable to those offered by commercial recorders. The device's bandwidth is adequate for EEG measurements and its CMR exceeds the minimum set out in the American Clinical Neurophysiology Society (ACNS) guidelines [ACNS, 2006]. Furthermore, the adapter's high input impedance ensures that the EEG can be measured even in situations where the electrode impedance is high.

The quality of the measured signal is excellent, as illustrated numerically by the supernal CMR and SNR values (see Table 3), and graphically in **Figure 3**. Since the two tracings are almost perfectly identical, this figure proves that the adapter does not distort the EEG signal in any way.

Table 2. *Summary of the adapter's characteristics.*

Parameter	*Value*
No. EEG Channels	1
Minimum Bandwidth (Hz)	0.171 – 500 000
CMR (dB)	90 – 110[1]
Input impedance (GΩ)	100[1]
Max. operating time (hours)	19.1
Max. standby time (hours)	26.9

Table 3. *SNR of the Neuroscan and of the 1-channel system over the 0.184 – 100 Hz frequency range.*

System	*Signal (μV_{RMS})*	*Noise (μV_{RMS})*	*SNR (dB)*
Neuroscan	34.07	0.46	37.39
Adapter	34.39	0.30	41.19

4. Discussion

Prior work has demonstrated that the information contained in the EEG is valuable in several emergent conditions, e.g., seizures and status epilepticus [Brenner, 2009; Praline et al., 2007], encephalopathies [Borges et al., 2010], identifying the etiology of altered mental states and comas [Bautista et al., 2007]. However, due to the shortcomings of conventional recorders (i.e., large dimensions, technical complexity, long preparation time) and the lack of guidelines regarding its use in emergencies, the EEG has remained underused in EM [Brenner, 2009; Bautista et al., 2007]. Moreover, no EEG recording system exists at the time of this writing that is specifically intended for use in emergencies. In this study, a portable EEG-to-ECG adapter has been developed that allows a patient's EEG to be recorded using the same infrastructure that is currently used for the recording of the ECG. Since the adapter is especially intended for use in emergency situations, it is small, portable, and can be applied quickly. Furthermore, preliminary results obtained using the adapter show that it can be employed in order to record high quality EEGs.

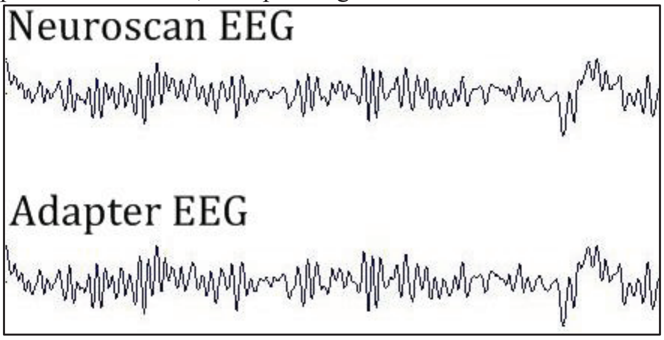
Since no specialized medical personnel is needed in order to operate the adapter, the recording method envisaged is much simpler than traditional EEG recordings, but also less expensive. Moreover, the clinical data that will be gathered by means of these two systems in ambulances, ERs, and ICUs could help in establishing guidelines for the application of EEG in emergency situations.

One limitation of the developed device is that it only allows the monitoring of one channel of EEG. According to the ACNS guidelines [ACNS, 2006], in order for an EEG recording to be considered comprehensive, all 21 electrodes of the 10-20 system are required. However, these guidelines were developed for routine EEG measurements and were not intended for emergency use. Hence, clinical testing is needed in order to determine whether the locations that have been chosen are sufficient in order to quickly determine a patient's neurological condition, and also whether more measurement locations are needed for this purpose. One factor that may place an upper bound on the number of channels that can be recorded is that a standard patient monitor can display only three ECG channels at

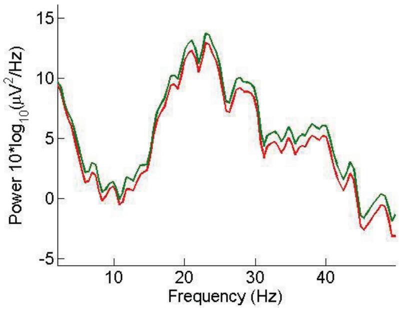
[1] Value was estimated from the circuit design.

any one time. Hence, a method for displaying more than three signals on a standard patient monitor must be devised if the number of EEG channels is to be increased.

A number of enhancements will be carried out in order to further improve the current adapter's performance. First, the operating time will be increased to at least 24 hours. The easiest way to achieve



(a) Time domain comparison.



(b) Power spectrum comparison (Neuroscan = green, EEG-to-ECG adapter = red).

Figure 3. *Comparison of the EEG recorded with the Neuroscan and the EEG-to-ECG adapter.*

this goal is by replacing the battery with a higher capacity one and by optimizing the current consumption of the adapter's circuitry. Second, alternative charging methods, such as inductive charging, will be explored in order to avoid having to make a hole in the adapter's enclosure for the mini-USB socket.

A final issue that needs to be resolved is the location of the transient protection resistors. Due to their substantial size and large cost, the resistors are not included in the present version of the adapter. Instead, their presence is simulated with surface-mount resistors placed in series with each input channel. Ideally, they should be placed within the adapter enclosure so that they can benefit from the protection it affords. However, the resistors' large size makes this option unpractical. Another solution is to build the resistors into the input electrode leads. While this would save space within the enclosure, it would also make heat dissipation more straightforward.

The next step in the development process is to test the adapter in a clinical environment. This testing will take place in the Helsinki University Central Hospital where a study involving a prototype of the adapter had already been approved by the Ethical Committee of the Hospital District of Helsinki and Uusimaa in 2009. One novel aspect that could be investigated as part of a future study is the minimum number of channels that is required in order to get a quick overview of a patient's neurological state. The results of such a study would determine the amount of channels that should be implemented in a future version of the adapter.

5. Conclusions

In order to overcome the barriers that prevent the widespread use of EEG in emergency medicine, we have developed a one channel EEG-to-ECG adapter that allows a patient's EEG to be displayed and recorded by any ECG device. Preliminary results indicate that the quality of the signals recorded in this fashion is similar to that of a commercial Neuroscan system.

Acknowledgements

This work was supported in part by the Finnish Funding Agency for Technology and Innovation (Tekes) through the EEG in emergency medicine project and in part by the Instrumentarium Science Foundation.

References

Alehan FK, Morton LD, Pellock JM. Utility of electroencephalography in the pediatric emergency department. *Journal of Child Neurology*. 16(7): 484 – 487, 2001.

American Clinical Neurophysiology Society (ACNS). Guideline 1: Minimum technical requirements for performing clinical electroencephalography. *Journal of Clinical Neurophysiology*. 23(2): 86 – 91, 2006.

American Clinical Neurophysiology Society (ACNS). Guideline 8: Guidelines for recording clinical EEG on digital media. *Journal of Clinical Neurophysiology*. 23(2): 122 – 124, 2006.

Bautista RE, Godwin S, Caro D. Incorporating abbreviated EEGs in the initial workup of patients who present to the emergency room with mental status changes of unknown etiology. *Journal of Clinical Neurophysiology: Official Publication of the American Electroencephalographic Society*. 24(1): 16 – 21, 2007.

Benbadis SR. Use and abuse of stat EEG. *Expert Review of Neurotherapeutics*. 8(6): 865 – 868, 2008.

Borges MA, Botós HJ, Bastos RF, Godoy MF, Marchi NS. Emergency EEG: study of survival. *Arquivos De Neuro-Psiquiatria.* 68(2): 174 – 178, 2010.

Brenner RP. How useful is EEG and EEG monitoring in the acutely ill and how to interpret it? *Epilepsia*. 50(12): 34 – 37, 2009.

Farnarier G. Indications urgentes de l'EEG dans la situation d'un traumatisme crânien, chez l'enfant et chez l'adulte. *Neurophysiologie Clinique/Clinical Neurophysiology*. 28(2): 121 – 133, 1998.

Hooshmand H, Maloney M. The role of EEG in the emergency room. *Clinical EEG (electroencephalography)*. 11(4): 163 – 168, 1980.

Kothare SV, Valencia I, Legido A. Emergent EEG is helpful in neurology critical care practice. *Clinical Neurophysiology*. 117(3): 698 – 699, 2006.

Markand ON. Pearls, perils, and pitfalls in the use of the electroencephalogram. *Seminars in Neurology*. 23(1): 7 – 46, 2003.

Praline J, de Toffol B, Mondon K, Hommet C, Prunier C, Corcia P, Lucas B, Autret A. EEG d'urgence : indications réelles et résultats. *Neurophysiologie Clinique/Clinical Neurophysiology*. 34(3-4): 175 – 181, 2004.

Praline J, Grujic J, Corcia P, Lucas B, Hommet C, Autret A, de Toffol B. Emergent EEG in clinical practice. *Clinical Neurophysiology.* 118(10): 2149 – 2155, 2007.

Tatum W. Long-term EEG monitoring: a clinical approach to electrophysiology. *Journal of Clinical Neurophysiology: Official Publication of the American Electroencephalographic Society*. 18(5): 442 – 455, 2001.

Thomas P. Status epilepticus: indications for emergency EEG. *Neurophysiologie Clinique/Clinical Neurophysiology*. 27(5): 398 - 405, 1997.