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A system for synchronous acquisition of selected physiological signals aimed at emotion recognition

***Abstract**. This article contains a description of a data acquisition system that enables simultaneous recording of selected human physiological signals, resulting from brain electrical activity, eye movement, facial expression and skin-galvanic reaction. The signals, recorded using various types of sensors/devices, are fully synchronized and can be used to detect and identify emotions.*

***Streszczenie.** W artykule zamieszczono opis autorskiego stanowiska badawczego umożliwiającego równoczesną rejestrację wybranych sygnałów fizjologicznych człowieka, powstałych w efekcie elektrycznej aktywności mózgu, ruchu gałek ocznych, mimiki twarzy oraz reakcji skórno-galwanicznej. Sygnały zarejestrowane z użyciem różnego typu czujników/urządzeń są ze sobą w pełni zsynchronizowane i mogą być wykorzystane do wykrywania i rozpoznawania emocji. (**Stanowisko badawcze do rejestracji wybranych sygnałów fizjologicznych na użytek rozpoznawania emocji**).*

Keywords: emotion recognition, electroencephalography, EEG, facial expression, GSR, eye-tracking, biosignals
Słowa kluczowe: rozpoznawanie emocji, elektroencefalografia, EEG, mimika twarzy, GSR, okulografia, biosygnały.

Introduction

Analysis and recognition of human emotions is a current research topic, on which a number of scientists are working. The topic is important because proper recognition of emotions can be useful in improving man-machine interaction and in designing effective user interfaces [1]. Recognition of emotions is also used in testing emotional reactions of consumers to marketing content. Studies on emotions are also an important subject within cognitive and clinical psychology [2].

Information about the emotional state of a person can be read from various physiological signals. In this respect, electrocardiography (ECG), electroencephalography (EEG), electromyography (EMG), electrooculography (EOG) and galvanic skin response (GSR) are commonly used [3]. Physiological signals are often supplemented by tracking eye movements (ET) and the analysis of facial expressions (FE). Numerous studies have focused on analysis and recognition of emotions based on a single biosignal [4–6]. However, studies are also carried out on the use of several physiological signals, recorded at the same time. This makes possible a more complex data analysis, based on data fusion, and increases the efficiency of emotion classification [7,8]

Acquisition of multiple physiological signals and their synchronization in time is a challenging task undertaken in many studies [7,8]. The most complex test apparatus are used primarily in medical applications [9]. The main problem is that each measuring instruments supported by a different programming interface and uses specific libraries. The problem may also be a pathway to signal acquisition, especially different sampling frequencies. There are known commercial solutions that integrate several sensors, but these are very expensive. In addition, highly important is the synchronization of the recorded physiological signals with the presented stimulus material (usually multimedia).

The authors have undertaken the task of constructing a system for simultaneous recording of brain electrical activity (EEG), eye movements (ET), facial expressions (FE) and galvanic skin-response (GSR). The appropriate signals are recorded during the presentation of multimedia content (stimulus)to the user. The implemented software, developed within the C# environment, enables the registration of physiological signals using several popular devices from different manufacturers. It also enables accurate synchronization of the recorded signals with the presented audio/video material.

Hardware

Hardware incorporated within the proposed system consists of the following devices (Fig. 1):

A - an EEG amplifier and active electrode cap,
B - a device for recording facial expressions (FE),
C - an eye-tracker,
D - a device for measuring skin resistance (GSR)
E - a computer as a system controller (not visible)

Fig.1. The developed system, A - EEG, B - Kinect, C - eye tracker, D – GSR

A. EEG

Electroencephalography (EEG) is a non-invasive method used to study brain activity [10]. According to many studies, the EEG signal carries valuable and objective information about the emotions [4,8]. The developed system enables registration of EEG signals by using one of the following pieces of commercial equipment:

- 16-channel g.USBamp amplifier (g.Tec),
- 14-channel EPOC amplifier (Emotiv),
- 5-channel Insight amplifier (Emotiv),
- 1-channel MindWave amplifier (NeuroSky).

B. Facial expressions

Facial expressions are the natural way to express emotions as well as to recognize them in everyday communication among people [11]. Each person is able to recognize emotions, based on facial expression, in a very easy way. The naturalness and simplicity of recognition of emotions through facial expressions have made them the most frequently used in this respect. To obtain information about the facial expressions in the developed system, the Microsoft Kinect device was used. Kinect uses two cameras and an infrared emitter [12]. One of the cameras records visible light, while the other operates in infrared and is used to measure depth in 3D space and to find the spatial coordinates (121 characteristic points of a face).

C. Eye-tracking

Eye-tracking allows the study of eye movements. Recorded signals enable the determination of eye position and the location of fixations(the areas on which a user rests his gaze)during visual presentation. Eye tracking data are often supplemented with measurement of eye pupil diameter, which can also be used in emotion recognition [13]. The developed system supports the following commercial eye-trackers:

- Eyetribe eyetracker,
- Tobii X2-60,
- Tobii Pro X3-120.

D. Galvanic skin response

Emotions have a significant impact on skin conductivity; hence, the measurement of galvanic skin response (GSR) [5] can be used to determine the emotional state of a respondent, and as an indicator of his/her excitation [14]. The changes in conductivity are caused by skin eccrine glands [15]. These glands are most numerous on the skin of the hands and feet. Generally, the signal is measured on the hand between the index and middle fingers. We used our own GSR system based on an Arduino Uno module.

E. Computer

The minimum requirements for a computer to enable proper system control are: Dual-Core 2,66GHz processor, 8GB of RAM, a graphics card supporting DirectX 9.0c, USB 2.0 or 3.0.

Software

The software was prepared using software development tools (SDK) provided by the device manufacturers. A graphical user interface (GUI) was created using Microsoft the .NET Framework and Windows Forms technology.

The main function of the developed software is to record a set of physiological signals during video playback using ActiveX technology. Such a solution enables communication with Windows Media Player. The software allows visualization of the recorded signals. It is also possible to preview the image from the Kinect camera (with the characteristic points of a face) and eye positions registered by the eye-tracker. This visualization allows verification of the quality of the recorded physiological signals and the correctness of the user position in relation to devices. The eye tracker should be calibrated before use. The main program window is shown in Fig. 2. Before experiments, it is possible to select a specific piece of equipment to use and the default folder to store data. Prior to registration of an EEG signal, it is necessary to check if the electrodes firmly adhere to the scalp. In turn, the registration of facial expressions and eye tracking requires the user to take up an appropriate position and distance in relation to the devices. In the main window preliminary information about the correctness of the recorded data is displayed.

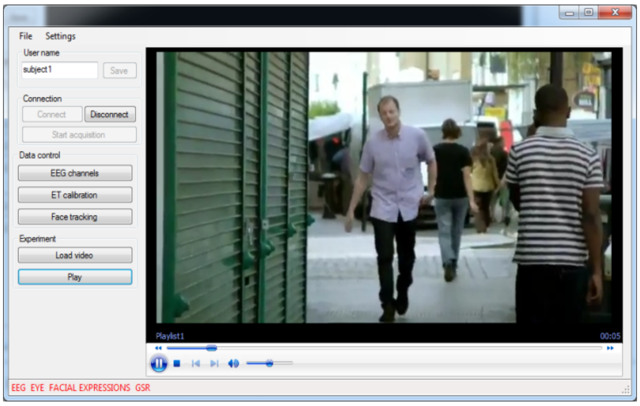

Fig. 2. GUI for recording physiological signals – main window

System functionality

One of the requirements for signal acquisition in emotion recognition is their recording without losses and delays both in relation to other physiological signals and to the presented video stimuli. Software tests were conducted using the following equipment:

- g.USBamp EEG amplifier,
- EyeTribe eye-tracker,
- Kinect device
- Our own GSR sensor.

The g.USBamp amplifier enables EEG signal registration from 16 channels (ADC with maximum sampling rate 38.4kSa/s and 24-bit resolution)[16]. The EyeTribe eye-tracker allows recording of the *x* and *y* screen coordinates expressed in pixels, on which the user gaze was directed, and information about fixations and pupil diameter. The data can be recorded with a speed of 30 or 60Sa/s. The recording is possible at a distance of 45-75cm from a monitor screen, with a maximum screen diagonal of 24 inches. An example of registered EEG signals is presented in Fig. 3.

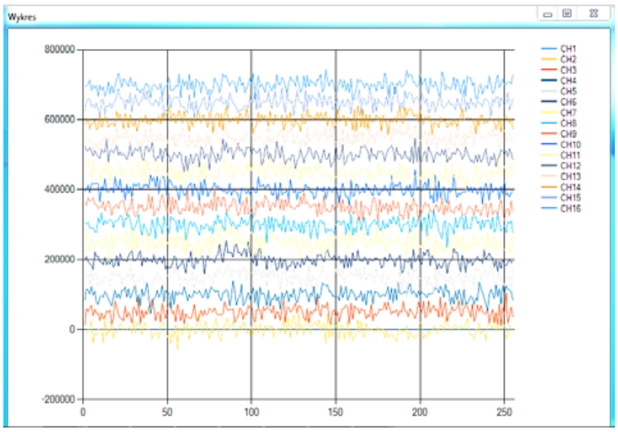

Fig. 3. Example of registered EEG signals

In the following figures the results of eye-tracker operation are presented. In Fig. 4a, distribution of fixations (blue point clusters) and sight paths between the fixations (arrows) are shown. The signals were recorded during a simple experiment in which the user objective was to direct their sight on markers (black circles) appearing on the screen. The changes in the *x* and *y* coordinates (describing fixations) over time are shown in Fig. 4b.

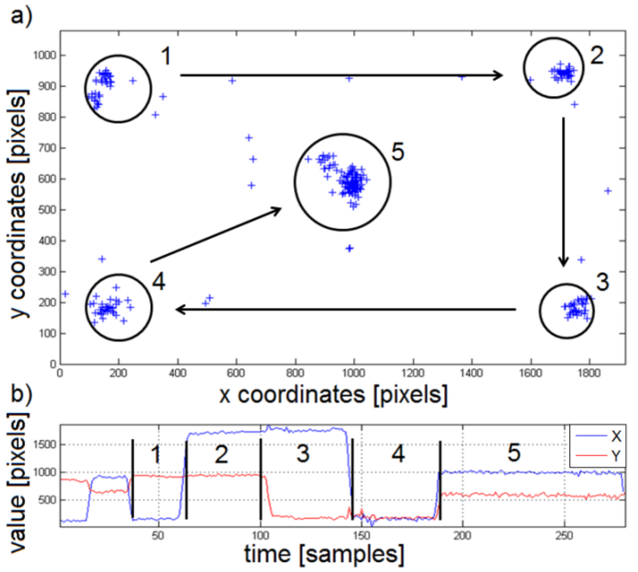

Fig.4. Fixations on screen (a) and changes in x and y coordinates (describing fixations) over time (b)

Analysis and presentation of eye movements is mainly done in graphical form. The results are placed on the observed image. In Fig. 5, sample results from the eye-tracker obtained for a 10-second presentation of an image are shown. Fixations are illustrated in the form of points (left side) and in the form of a heatmap (right side). The greatest concentration of fixations are illustrated on the heatmap by orange colour.

Fig.5. Fixation points and heatmap placed on the tested image

In order to recognize facial expressions, the Kinect device records the spatial coordinates of 121 characteristic points on the face. In addition, Kinect calculates 6 coefficients named animation units (AU). These coefficients take values between -1 and 1, and carry information about:

1. Upper lip raising (AU0)
2. Jaw lowering (AU1)
3. Lip stretching (AU2)
4. Lowering eyebrows (AU3)
5. Lip corner depressing (AU4)
6. Outer brow raising (AU5)

These coefficients have been selected by the manufacturer of Kinect, among many introduced by Ekman and Friesen in the “Facial Action Coding System” [17].The coefficients can be used singly or in combinations to describe emotions [18]. In Fig.6, the characteristic face points (a) and change in the AU1 coefficient during the transition from closed to open mouth (b) are shown. AU coefficients and characteristic points on face are registered at a rate of 30Sa/s. Data are recorded only if the user's face is detected correctly. Face recognition is possible at a distance from 80cm to 4m.

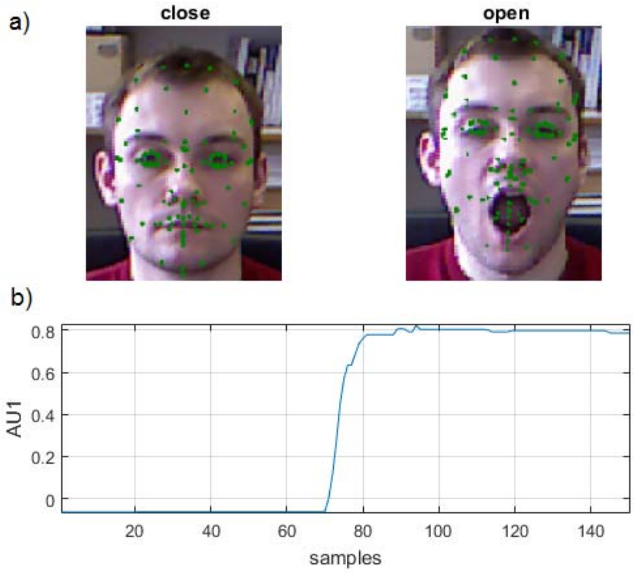

Fig.6. AU1 coefficient for closed and open mouth

The author’s GSR recording device operates at a speed of 10Sa/s with 10 bit resolution. An increase in the signal value is associated with an increase in skin conductance caused by sweating. This means the activation of the autonomic nervous system which may be associated with emotions. In Fig.7, an example of the GSR signal waveform is shown.

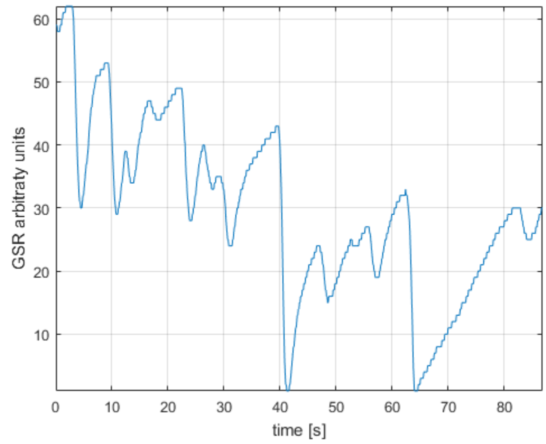

Fig.7. Registered GSR signal

System tests

In the developed system, each implemented acquisition module uses CPU and RAM resources. So, it was necessary to verify system operation by effecting the acquisition of all the signals simultaneously. The system was subjected by the authors to rigorous tests. It was checked to see whether there were no lost samples and whether the recorded signals were properly synchronized. In the first stage, we validated the number of samples recorded over a predetermined period of time. Signals were recorded during the presentation of a test video (duration of

86.95s). Table 1 presents the following verification test results: sampling frequency, potential number of samples for registration, number of samples recorded, and the percentage of lost samples.

Table 1. Test of the number of registered samples

Device	Sampling Rate [Hz]	Samples to record [S]	Samples recorded [S]	Samples lost [%]
g.USBamp	512	44518	44559	0,0%
EyeTribe	60	5217	4697	9,9%
Kinect	30	2609	2601	0,3%
GSR	10	869	882	0,0%

In the case of the eye-tracker (EyeTribe), 9.9% of the samples which should have been recorded during the film presentation were lost. The loss of samples was only due to the quality of the device [19]. On the other hand, the g.USBamp captured more than the theoretical number of samples. The reason for this was the presence of a delay between the film played in Windows Media Player and the appearance of markers that allow events in the registered data to be found. Forty-one redundant samples were registered, which corresponded to about 80ms of delay.

Next, we conducted tests of synchronization quality between the signals coming from various devices. Differences in the sampling rates of each device mean that, prior to analysis, the recorded signals should be interpolated. In the test, signals were linearly interpolated to 512Sa/s. In Fig. 8, one-second chunks of recorded signal waveforms before and after the process of interpolation are shown. The correctness of signal registration and interpolation was verified by visual inspection.

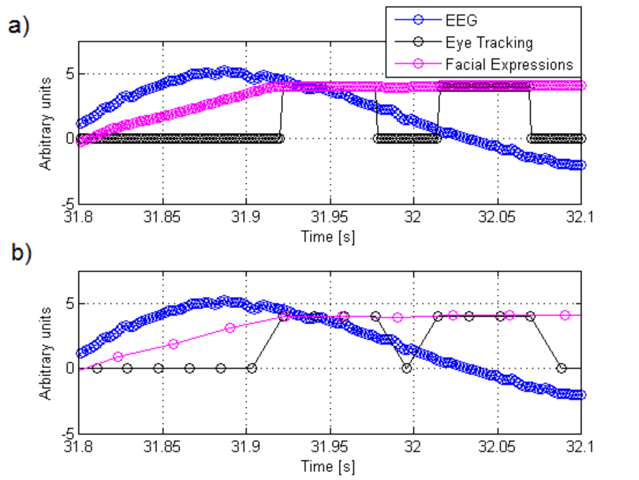

Fig.8. Examples of the recorded signals after (a) and prior to (b) interpolation

During the experiment, text commands with suggested actions were presented: blink, lower the jaw, open your mouth, smile, etc. The user task was to perform the suggested actions, which resulted in the generation of facial muscle potentials (EMG) and creation of artifacts in the registered EEG signal. Generally, the amplitude of muscle potentials is much higher than the amplitude of pure EEG signals, so the signal is clearly visible in the registered EEG - as artifacts. This effect can be used in the synchronization procedure.

In Fig. 9, a sample EEG signal (from T7 electrode) and AU1 coefficient variability (jaw lowering - from Kinect) are presented. Location of the T7 electrode near the face means that the EEG signal is greatly disturbed by artifacts from face mimic muscles. The moment of the command "lower the jaw" was marked with a black vertical line. The person has responded to the command with a delay of approximately 0.75s. Artifacts caused by jaw movement are easy visible in the EEG signal. Also, Kinect AU1 coefficient values change indicating the moment of jaw lowering or clamping.

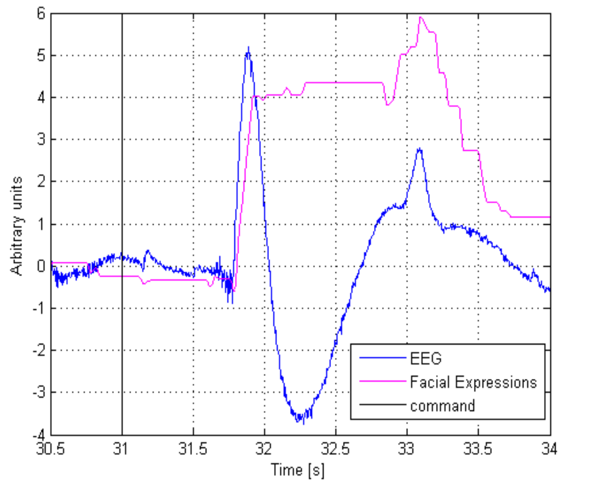

Fig.9. The EEG signal and the value of AU1 coefficient after the command for jaw lowering

In Fig. 10, the EEG signal from the Fp1 electrode and eye tracking signal with triple, rapid eye blinks are presented.

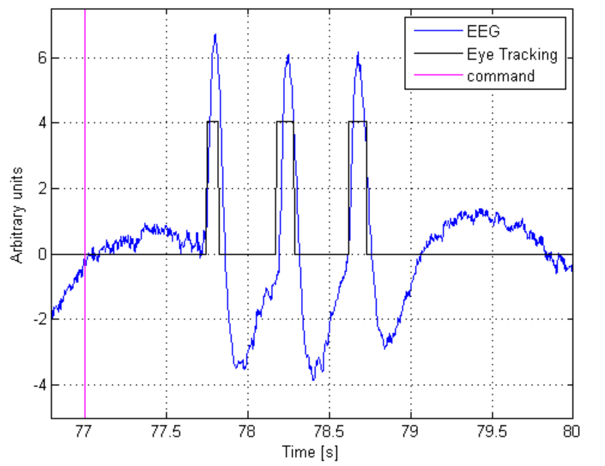

Fig.10. EEG from Fp1 electrode and eye tracking signals with triple eye blinks.

The Fp1 electrode is located in the prefrontal cortex area, so the signal from it is sensitive to EMG artifacts from eye and facial muscles. The signal from the eye-tracker has binary form: equaling 1 for closed eyes and 0 for open eyes. Triple eye blink caused artifacts in the EEG which were seen as sudden surges in amplitude. The surges occurred exactly at the time the user closed his/her eyes. Such tests using muscle artifacts prove the correctness of the synchronization of physiological signals recorded with the use of the system.

The difficulty of synchronizing of GSR signal, due to motion artifacts, prevented the use of this signal in testing. Proper synchronization of other signals indicate correct operation of the whole developed system.

Conclusions

The tests showed that the developed system could be successfully used for synchronous registration of selected physiological signals. Despite the lack of complex solutions for synchronization, the delay between the playing of the film and the recorded signals was very small. Data recorded from individual devices were synchronized with one another to use them in practice. We hope that the developed solution, enabling simultaneous recording of brain activity signals, facial expressions, galvanic skin response and eye tracking, can greatly improve the efficiency of emotion recognition and user reaction to played multimedia content.

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