

AKADÉMIAI KIADÓ

# Development of EEG measurement and processing system in LabVIEW development environment

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ORIGINAL RESEARCH PAPER



## ABSTRACT

Our research team has developed a system and methodology for measuring psycho-physiological parameters, which can be used to determine the level of fatigue and fitness of the person being measured. This article describes the electroencephalography (EEG) part of this system. This article covers the technical and mathematical background of EEG measurement, the selection and implementation of the measurement tool in the development environment, and the development of the measurement and processing algorithm. The result is a system that can detect, digitize, and process the digitized signal from the brain, and save the processed signal in an XML database.

## KEYWORDS

EEG, LabVIEW, XML, FFT, adatbázis, Muse, UDP protokoll, Bluetooth low energy, OSC protokoll

## 1. INTRODUCTION [1]

Electroencephalography (EEG) is a non-invasive measurement procedure for detecting electrical signals from the brain and then processing these signals. With the help of signals from the brain, we can determine the current state of the human mind and track the change to certain external stimuli from the ground state. Fixing the baseline is a critical point for EEG measurements, since every person has a different datum elsewhere, it is not possible to add a single datum for each person. Compared to the correctly recorded baseline condition, we can draw conclusions that the subject's mental state has deteriorated or improved as a result of certain stimuli. Deeper, more comprehensive analysis requires serious neurological knowledge, but simpler, but more important analyses can be performed by simple mathematical calculations.

For example, surveying the mental health of those involved in extreme work is an area of application that has shown rapid development and need for further research. This includes performing the aforementioned resting measurement, which is important for the subject to be calm and relaxed. After resting, it is possible to re-examine the physical or mental subject to see how your brain responded to the exercise. Typically, these jobs include pilots, fire-fighters, air traffic controllers, ambulances.

The purpose of this research is to create a system that can quantify the fatigue and fitness status of a person and store this data in a database. The complete system includes an ECG gauge, an EEG gauge, a vascular stiffness gauge, a muscle oxygen level gauge, and a skin temperature gauge. The data processed must be credible in order to provide an expert with relevant data.

This paper is part of a larger research project, further results will be published in [18, 19].

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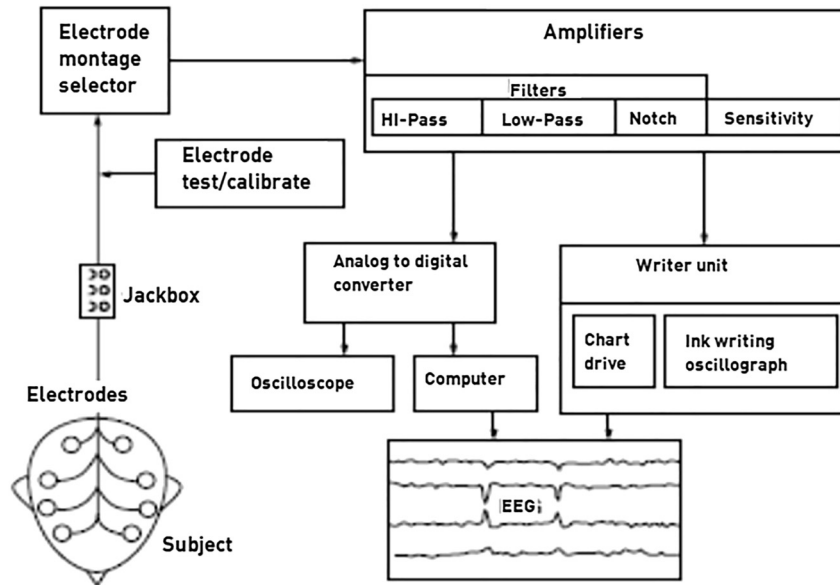


Fig. 3. Generic EEG system block diagram [8]

for this is the Fast Fourier Transform, or FFT, which is a faster version of the discrete Fourier transform.

1. Butterworth filter

Butterworth filters are of the type IIR, or Infinite Impulse Response filters. Butterworth filters have the following characteristics:

- Damped amplitude function at all frequencies,
- The amplitude curve decreases monotonically from a given cut-off frequency,
- Maximum flatness, unit response in transmission band and zero in crop band,
- Half power frequency or 3 dwindling frequency is related to cutting frequency,

The great advantages of Butterworth filters are their smoothness and monotonically decreasing frequency function, so they do not distort the signal even when properly filtered (Fig. 4).

$$H(j\omega) = \frac{1}{\sqrt{1 + \varepsilon^2 \left(\frac{\omega}{\omega_p}\right)^{2N}}} \quad (1)$$

where:  $N$  is the filter order number,  $\omega = 2\pi f$  is the frequency variable,  $\omega_p$  is the cut off frequency,  $\varepsilon$  is the maximum gain and  $H$  is the filter response (transfer function in the complex frequency domain).

1. FFT algorithm [10]

FFT, or fast Fourier transformation, is essentially a faster version of a classic Fourier transformation. In the direct implementation of the discrete Fourier transform, we need to perform approximately  $N^2$  complex operations on  $N$  samples, which is a very time-consuming calculation operation.

Fast Fourier Transform (FFT) is a (fast) algorithm that can be used to calculate DFT. The following equation gives the DFT transformation formula:

$$X[k] = \sum_{i=0}^{N-1} x[i] * e^{-j\left(\frac{2\pi i k}{N}\right)} \quad k = 0, 1, 2 \dots N - 1. \quad (2)$$

where:  $X [n]$  values are the time domain values of the sampled signal,  $N$  is the number of sample values.

The FFT and the power spectrum are very useful for measuring the frequency content of steady and transient signals. The FFT gives an average frequency content over the entire measurement range. Therefore, FFT is useful when the signal is steady state or when an average power content is required at each frequency. The frequency spectrum

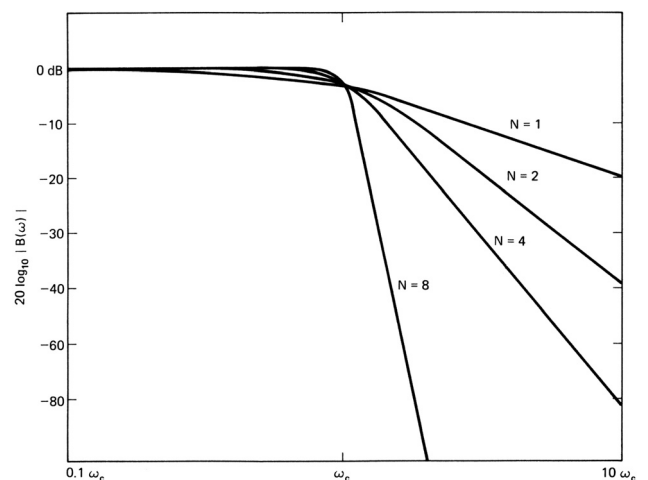
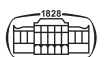


Fig. 4. Butterworth filter Bode diagram with different order numbers [9]



obtained from the EEG signal can be classified into the notable frequency bands shown in Table 1:

### 3. SELECTING THE EEG MEASURING INSTRUMENTATION [11]

The development procedures started with the selection of proper EEG device that is properly authenticated, can communicate wirelessly and is easy to install to patient and use by non-technical experts as well. There are many EEG metering systems on the market for sport, meditation, and medical applications, in variable price ranges. Our selection was the Muse 2016 EEG instrument, which can detect EEG signals with the same accuracy as a laboratory instrument, and comes with a manufacturer-supplied Application Programming Interface (API) for quick integration into any development environment and facilitating the development process [12].

Muse EEG is a 4-channel EEG measurement device capable of delivering real-time data of EEG signals via wireless connection (Bluetooth Low Energy 4.2.) (Fig. 5)

The technical parameters of the Muse EEG are shown in Table 2.

Table 1. EEG frequency bands and their characteristics

Name	Frequency	Features
$\delta$ -delta	Less than, 4 Hz	Fastest and strongest brain wave, very low frequency, high amplitude. Usually deep sleep or sleepless sleep. It is also found in deep meditation.
$\theta$ -theta	4-8 Hz	Drowsiness, light sleep, deep relaxation or meditation.
$\alpha$ -alpha	8-12 Hz	Relaxation, tranquility or peace.
$\beta$ -beta	12-30 Hz	Normal waking awareness, high alert, active thinking, anxiety or focus. Most people work in this band during the day.
$\gamma$ -gamma	More than 30 Hz	Fastest brainwave. Hyperactivity or processing of information from different brain areas.



Fig. 5. Muse EEG [11]

The device is capable of real-time monitoring of brain waves on 4 EEG channels with 256 [Hz] sampling rate and 12 [bit] resolution, and a 3-axis accelerometer and gyroscope are included to estimate head pose and movement. Pose and movement information will be useful later in the measurement as motion can cause disturbance in the signal, so if the EEG waveform and the accelerometer are both jumping and disturbed at the same time. Source of disturbance signal caused by the movement and jerking.

Fig. 6 clearly shows that the device uses 4 channels, two on the forehead and two behind the ear, with the reference electrode located in the center of the forehead (Fpz). This 4-channel EEG measurement system proved to be sufficient (in technical and financial terms) for this project, and it is possible to extract the data needed to assess the subject's state of mind [13]. Bluetooth wireless connection provides a stable connection in our office and laboratory use, for our measurement, but it should be noted that it may not be suitable for all possible application areas. Wireless connection may be disturbed by other wireless devices utilizing the same 2.4 GHz ISM band. Cooperation with other Bluetooth health care devices, such as smart watches or sleep monitors, was not tested.

### 4. MUSE EEG IMPLEMENTATION IN LABVIEW DEVELOPMENT ENVIRONMENT

#### 4.1. Pairing Muse EEG with your computer

A utility called Muse Direct needs to be installed from the Microsoft Store to connect the device to your computer. This application communicates with the device via a Bluetooth connection, and then transmits the incoming data to the processing program as an OSC (Open Sound Control) stream, UDP (User Datagram Protocol). Please note that Bluetooth was the lower level protocol and TCP/IP protocol was the higher level protocol, where UDP was applied (Fig. 7).

Clicking on the Bluetooth slider will start exploring and connecting to nearby Muse devices. After connection, you will receive information on signal quality and battery status.

Table 2. Muse EEG technical parameters

Wireless connection	BT 4.2 BLE
EEG channels	4 Measurement Channels 256 Hz sampling rate 12 bit/sample
Reference electrode position	FPz (CMS/DRL)
Channel electrode position	TP9, AF7, AF8, TP10 (dry)
Battery Time	Maximum 10 hours (rechargeable Li-Ion)
Accelerometer	Three-axis 52 Hz, 16 bit resolution, range $\pm 4$ g
Gyroscope	$\pm 1,000$ $^{\circ}$ /s



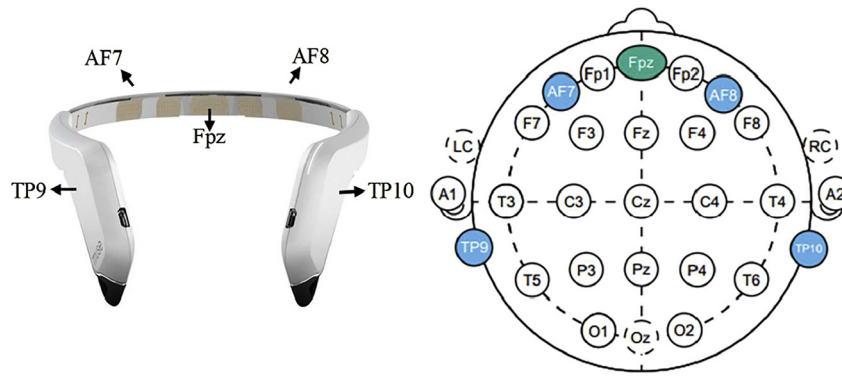


Fig. 6. Muse EEG distribution of electrodes [1]

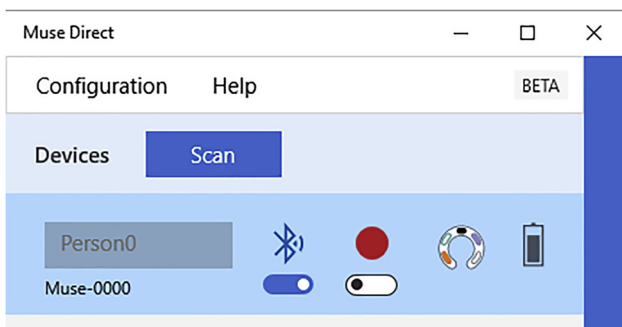


Fig. 7. Pair Muse EEG with Muse Direct [own figure]

Communication must be configured to provide LabVIEW with processable data (Fig. 8).

During configuration, you need to enter your computer's own IP address through any port, in this case 7,000, and then choose which data to provide.

#### 4.2. Implementing Muse EEG in a LabVIEW development environment

Implementing Muse EEG in the LabVIEW Developer Environment by completing the OSC data stream, LabVIEW performs post-filtering of data, graphs and graphs raw and calculated values, and saves measurement and configuration parameters in a .csv and .xml file extension.

##### 1. Read OSC stream

The OSC stream is transmitted through a UDP protocol to a processing program like the TCP/IP network protocol, except that the sending party does not wait for confirmation from the client whether it has received the data packet. This method provides faster communication than TCP (Transmission Control Protocol) but may result in data loss for a less resource intensive client. For this reason, the client, the processing program, must run on a powerful machine to minimize the time difference between iterations and to avoid packet loss. TCP packet waits for acknowledgment sent by receiver, so this wait may overload transmission buffers.

A feature of an OSC data stream is that it sends data in packets, with different addresses and arguments in the

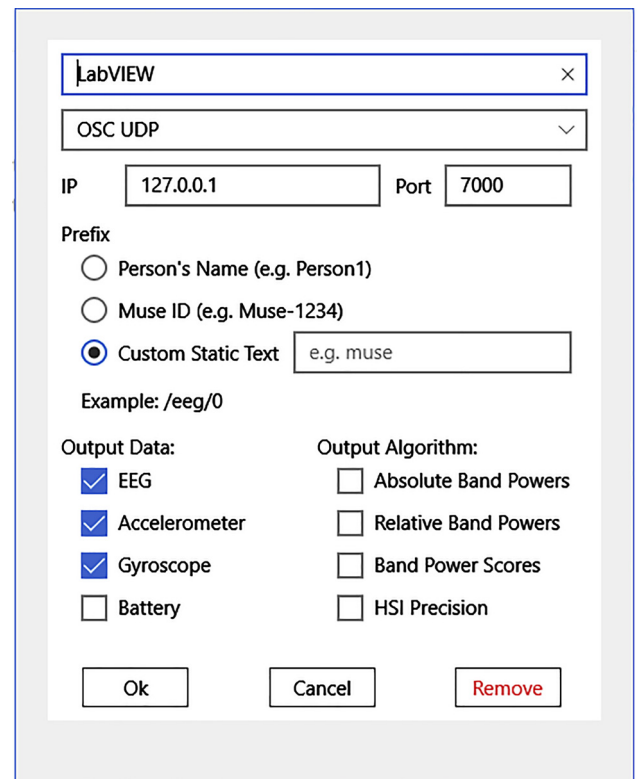


Fig. 8. Configure an OSC stream [own figure]

packets. Muse Direct sends the data according to the following encoding:

- **/notch\_filtered\_eeg**: raw EEG from which 50 Hz network noise is filtered
- **/acc**: accelerometer data
- **/gyro**: gyroscope data

LabVIEW can read these packages using an installable directory by setting the appropriate parameters and addresses. Inbound data is merged into a waveform, transformed from a quasi-digital signal to an analog signal [14].

Fig. 9 shows that the program first connects to the appropriate UDP port, but if no data is exchanged for 3 seconds, the program will stop (and generates exception)



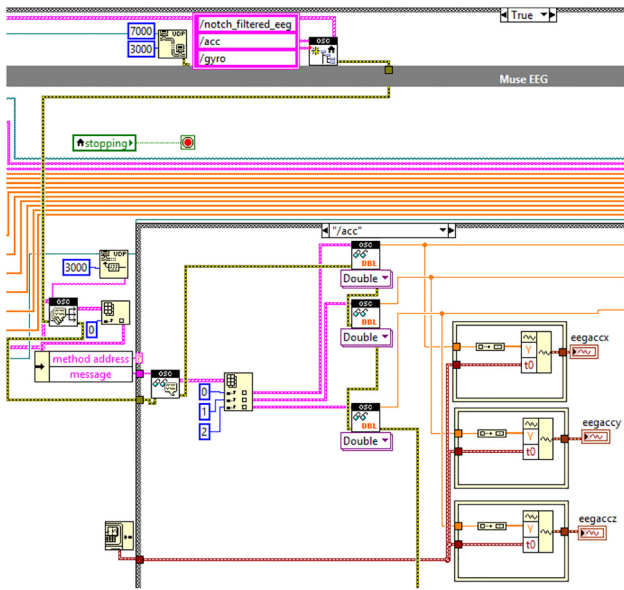


Fig. 9. OSC streaming reader and visualization program detail [own figure]

due to timeout. Once the connection is established, the data stream starts according to the OSC address table, which provides EEG, gyroscope, and accelerometer data from the device.

1. EEG signal filtering by Butterworth filter

The implementation of the filter in the program was inevitable as only the 50 [Hz] utility network components are physically filtered by the device from the input data, so the higher frequency interfering components are still present in the signal. To filter out low frequency component disturbances, such as blinking, muscle twitching, accidental movement, the parameters of the filtering algorithm were set to pass the components between 0.5 [Hz] and 35 [Hz]. With this EEG data bandpass filter, higher frequency components can also be filtered out.

Based on the results of some research [17], the optimal number for filtering the EEG is 2, which can be used to safely filter out interfering signals without distorting the signal. 0.5 Hz was selected because our measurements were done in a quiet and calm laboratory environment (Fig. 10).

The input to the filter is the array read from the OSC stream, and the output is the filtered signal that can then be processed.

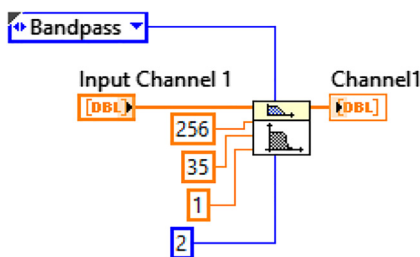


Fig. 10. Bandwidth Butterworth Filter Program Detail [own figure]

1. Calculation of spectral analysis for EEG channels

The cleaned data set is then converted from a time domain to a frequency domain using an FFT algorithm and then plotted using a graph to measure the average spectrum. According to our fitness/fatigue evaluation protocol we developed, a measurement lasts in quiet and calm environment for 6 minutes and is divided into 3 and 3 minutes. According to our investigation, it was suitable to provide information on the trend for the first and second half of the measurement [15] (Fig. 11).

The program calculates FFT for a total of 10 arrays, 4 channels for the first measurement, 4 channels for the second half of the measurement, and first and second half averages.

During the FFT calculation, the program also calculates the power of each frequency range, i.e. the area under the FFT graph. The area under the curve is used to determine the asymmetry between the right and left hemispheres. Obviously, the hemisphere that has higher average power at the time of measurement is the more dominant hemisphere.

Fig. 12 shows the frequency bands, which are marked with a separate color (Figs. 13 and 14).

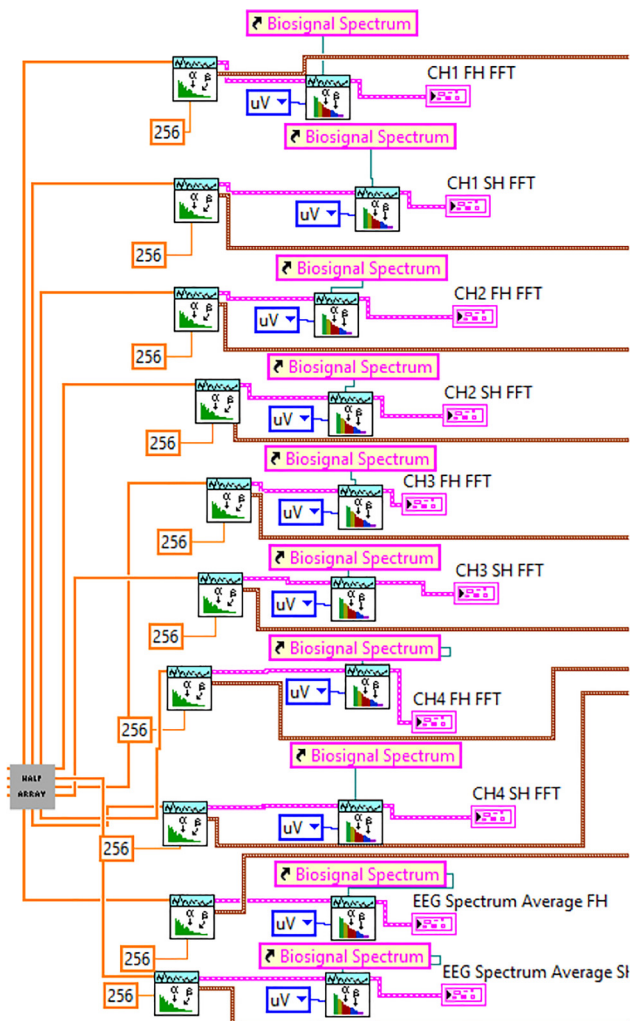


Fig. 11. FFT algorithm program snippet [own figure]



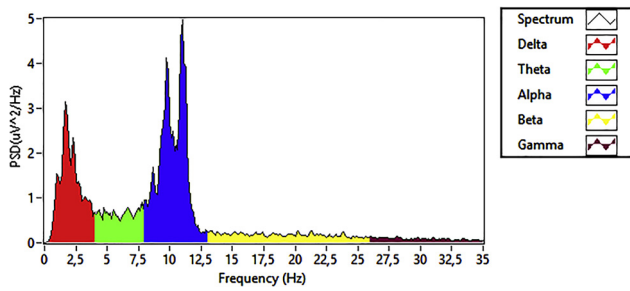


Fig. 12. FFT graph for EEG signal [own figure]

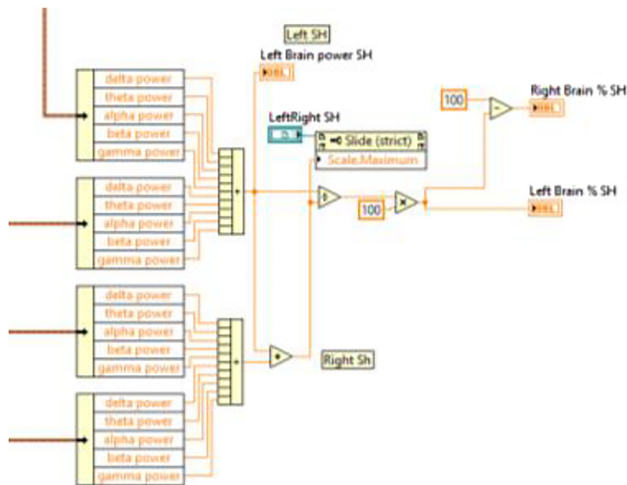


Fig. 13. Right/left hemisphere asymmetry calculation part [own figure]

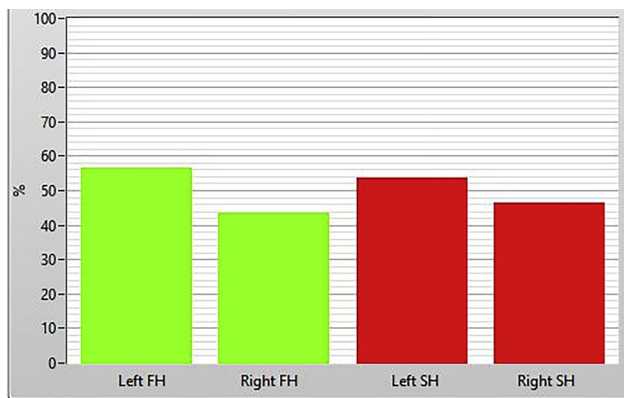


Fig. 14. Visualization of cerebral hemispheres asymmetry for the first and second half of the measurement [own figure]

1. Saving measurement data

At the end of the measurement, the measurement data is saved with headers and units in the .csv file extension. This format is selected because this extension can be interpreted by several popular data processing and display programs, so we have more options for re-measuring.

The filename composition applies the following system: "Muse\_measurement\_% Y-% m-% d. % H:% M:% S%

3u.csv". Since the date and time are saved, plus the seconds to 3 decimal places, it is possible to accurately differentiate and identify each measurement file.

After the measurement is started, the program creates an XML database in which the configuration settings are stored. The most important of these are the serial numbers of the devices, the name of the person performing the measurements, the resolutions of the devices, the sampling frequency, the path of the measurement file created after the measurement, the number of channels and the minimum and maximum values. This database can be used to validate the output of the measurement in terms of configuration parameters (Fig. 15).

5. TEST MEASUREMENT

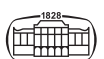
Measurement and testing of EEG signals was carried out with the assistance of a team of medical experts, including helicopter pilots. Measuring EEG signals first and foremost requires proper placement of the Muse, as this is the only way the device can provide valuable, processable signals. The device's data sheet states that it works with a dry electrode system, but for a perfect contact, it is advisable to moisten the surface of the electrode with a slightly damp or blue spirit cotton pad (Figs. 16 and 17).

```
<Muse>
<Serial_Number>2041-MRAR-DC26</Serial_Number>
<Devide_Id>Muse-DC26</Devide_Id>
<Channel_Number>4</Channel_Number>
<Sampling_Frequency Unit="Hz" Multiplier="1">
<Numeric_Value>256</Numeric_Value>
</Sampling_Frequency>
<Resolution Unit="Bit">
<Numeric_Value>12</Numeric_Value>
</Resolution>
</Muse>
```

Fig. 15. Configuration XML database [own figure]



Fig. 16. Professional medical assistance: Placing Muse on the test subject. The measurement was done with ECG measurement.



Before starting the measurement, the subject should be asked to close his eyes and move as little as possible, as these can cause interfering signals in the collected signals, which could greatly distort the measurement output.

The installation was in all cases done by an expert person, continuously monitoring the data collected by the device during the measurement. During the measurement the experts found everything was fine, and any fine-tuning was carried out on site (Figs. 18 and 19).

During the test measurement, the gyroscope and the accelerometer proved to be useful as these sensors can be used to detect whether motion was caused by a disturbance signal (some disturbing signals such as motion, jerking) or other external sources, interference (Figs. 20 and 21).



Fig. 17. ECG measurements was done in calm and quiet laboratory to minimize external disturbance may has effect on patient's mind state

Measurements are tracked using graphs that transmit measured data in real-time to provide an accurate view of the measurement process. You can display more than one graph on the graph at a time, so you can look for correlations between the waveforms of some measured values (Fig. 22).

The report calculates the data computed by all programs, the power, relative and absolute distributions of each frequency range, and the percentage distribution of the right and left hemispheres, all of which appear on the expert panel for the first and second half of the measurement (Figs. 23–25).

For the sake of clarity, the first and second halves of the measurement were distinguished in the hemispheric diagram by two colors, so that they can be clearly distinguished. And displaying a chart helps you keep track of the trend.

### 6. CONCLUSIONS

In this paper, we presented a technical method and evaluation logic to measure physical and mental fitness/fatigue. Commercially available, Muse EEG device was used for EEG measurement and LabView environment was used to develop evaluation logic. Butterworth filter was applied to remove unwanted noise from signal, then FFT was applied to convert time domain to frequency domain. The signal was classified according to common frequency bandwidths of brain signals: Delta, Theta, Alpha, Beta and Gamma. The area covered by FFT signals was also measured to decide the dominant left or right hemispheres.

In the end, the system is working as expected, all required functions have been successfully implemented. The system is stable, even for long-term continuous measurements. This paper is part of a larger research project, further results will be published in [18, 19].

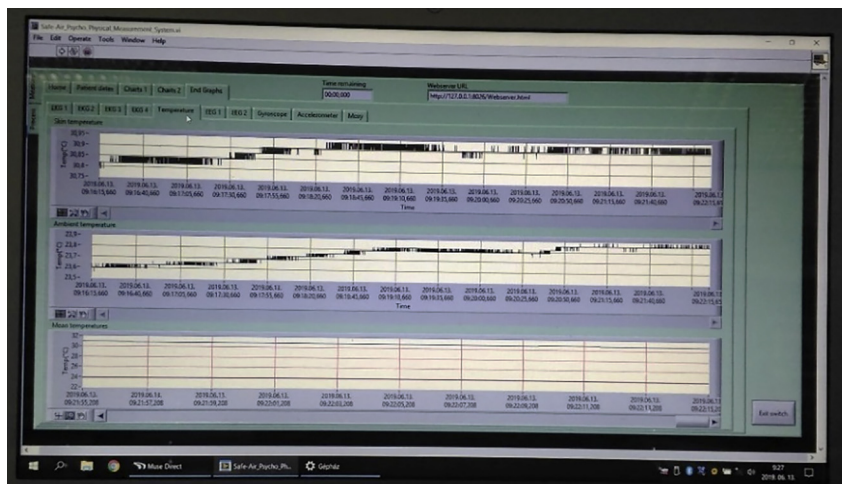


Fig. 18. Screenshot of test measurement with gyroscope on bottom graph



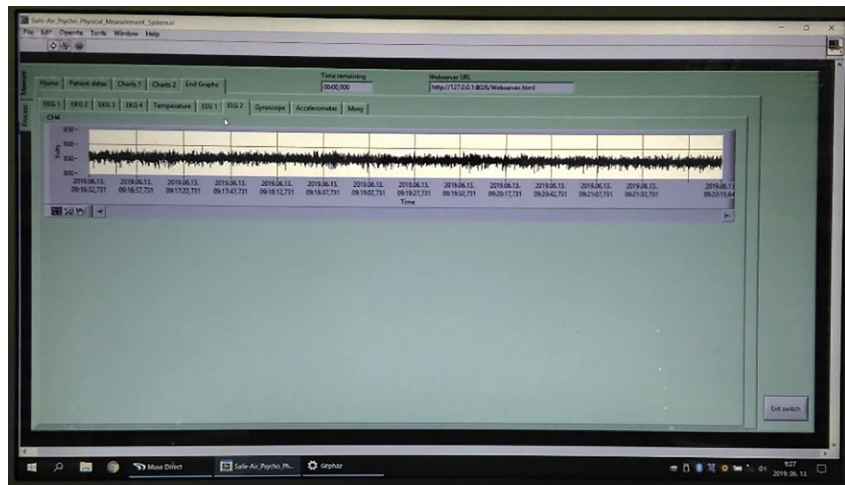


Fig. 19. Test Measurement Screenshot - EEG waveform

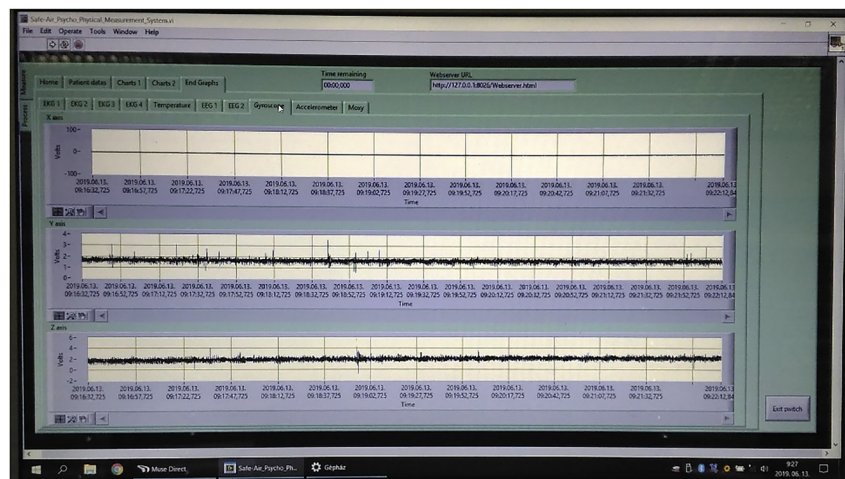


Fig. 20. Test measurement screenshot and EEG waveforms

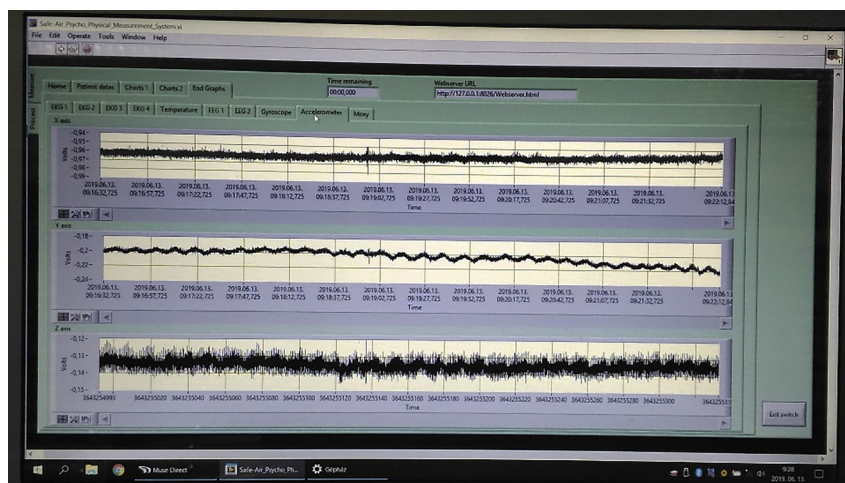
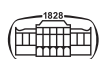


Fig. 21. Test Measurement - EEG and accelerometer waveforms



Drv Electrode EEG:

		First half	Second half
delta power	mV <sup>2</sup> /Hz	104,825022	6,028013
theta power	mV <sup>2</sup> /Hz	18,968508	3,312702
alpha power	mV <sup>2</sup> /Hz	19,650305	15,721921
beta power	mV <sup>2</sup> /Hz	19,768544	2,320949
gamma power	mV <sup>2</sup> /Hz	4,968980	0,318584
delta [%]	%	62,328562	21,760076
theta [%]	%	11,278603	11,958276
alpha [%]	%	11,683997	56,753395
beta [%]	%	11,754302	8,378220
gamma [%]	%	2,954536	1,150033
Left Brain [%]	%	75,952555	52,826684
Right Brain [%]	%	24,047445	47,173316

Fig. 22. EEG figures for a 24-year-old male in the report

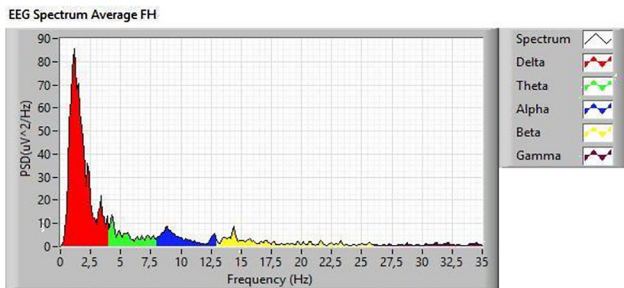


Fig. 23. EEG spectrum of a 24-year-old male – first half measurement

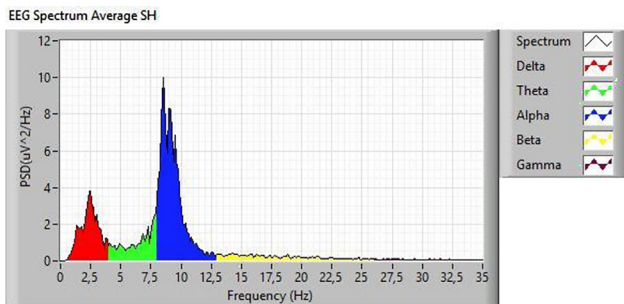


Fig. 24. EEG spectrum of a 24-year-old male – second half of measurement



Fig. 25. Bar graph of 24-year-old male cerebral hemispheric rate

The system offers a number of enhancements that can be used to extract even more data from the measurement data set:

- Application of Deep/machine learning algorithms to classify multiple measurements
- Creating a correlation matrix for the measurement parameters
- Prediction of mental illness

7. ACKNOWLEDGMENTS

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