Natalia Nikolaevna Shusharina et al /J. Pharm. Sci. & Res. Vol. 9(7), 2017, 1178-1183
ISSN:0975-1459
Journal of Pharmaceutical Sciences and Research
www.jpsr.pharmainfo.in

A Wireless Portable Platform for Physiological Potentials Registration and Processing: A Unified Approach

Natalia Nikolaevna Shusharina
Immanuel Kant Baltic Federal University (IKBFU)
Nevskogo Str., 14, Kaliningrad, 236041, Russia
Danil Aleksandrovich Borchevkin
Immanuel Kant Baltic Federal University (IKBFU)
Nevskogo Str., 14, Kaliningrad, 236041, Russia
Viktor Viktorovich Sapunov
Immanuel Kant Baltic Federal University (IKBFU)
Nevskogo Str., 14, Kaliningrad, 236041, Russia
Vitaliy Andreevich Petrov
Immanuel Kant Baltic Federal University (IKBFU)
Nevskogo Str., 14, Kaliningrad, 236041, Russia
Maksim Vladimirovich Patrushev
Immanuel Kant Baltic Federal University (IKBFU)
Nevskogo Str., 14, Kaliningrad, 236041, Russia

Abstract

The majority of modern human-machine interfaces are based on the registration of electro-physiological and biometric parameters of the human body, such as electroencephalography, electromyography and electrooculography signals. Although there is a number of scientific, medical and consumer equipment capable of biosignal registration, but each of them has its drawbacks. The immediate objective of this work is to design the modular platform for registration and onboard processing of electrophysiological and biometric data. The key features of the developed system are: capability to acquire different biosignals; universal serial interface for sensors and external devices connection; on-board complex data processing capability; high portability due to capacious battery and variety of available wireless interfaces. In the future work, the developed platform will be tested in real world applications.

Keywords: Neurodevice; Electroencephalogram; Electromyogram; Electrooculogram; Brain-computer interface; Neurotechnology.

1. INTRODUCTION

A variety of tasks dedicated to development of different equipment for the human-machine interactions stays actual for a long time and attracts attention of the scientific community. [1] There are a lot of different approaches in design of such type of interfaces, but bionic variations were proved to be the most "natural". In such interfaces, the instruction source mechanism is based on a set of electro-physiological and biometric parameters of the human body. The most popular types of biological signals are: electroencephalography (electric potentials of the brain), electromyography (electrical activity of the muscle's motor units) and electrooculography (corneo-retinal standing potentials measured during eyeball movements). [2] The main reason to use the abovementioned signals is the comparatively simple registration mechanism, which simplifies the development of the human-machine interface: low-cost consumables (electrodes and conductive gel), the opportunity to design a device on a single board (small size and portability), and availability of unified signal amplifiers to organize the system with several biological signal types inputs simultaneously. The latter seems to be even more interesting as a opportunity to use several biological modalities for accuracy improvement, electrophysiological patterns recognition and interface usability. [3] [4] Besides, such approach allows not only signal registration and processing, but also usage of different sensors for evaluation of physical condition and physiological parameters in real time.

The problem of design and development of a device for registration, processing and transmitting of the data on physiological activity of the human body can be divided into two categories: the technical aspects of the development process for separate components, and questions of design and structural schema. The first category includes questions of biological signal amplifier, electrodes, ADC and power management system design. [5] The second category consists of: portability, endurance, biological compatibility and usability for end-user. [6] Some of these questions became not such important because of the development of electronic components, new materials and 3D printing technology, which brought a number of new devices for bio-potential registration, including commercial ones (for example, Emotiv EPOC, Myo Armband, OpenBCI project, etc.). However, despite the availability of such devices, an optimal solution has not been found yet, and the development of human-machine interfaces is still one of the important topics for the science community.

Besides, a separate task of registration and initial processing of physiological signals on board is also important, as, in most cases, the whole problem requires feedback or drive command generation. That requirement became the core idea of the proposed device. A common rule of hybridism in signal processing should allow using the device as a tool for telemetry and processing platform for drive commands generation for external equipment. The paper [7] discusses portability aspects, points to directions of the development of number of such external equipment like orthoses, exoskeletons, remote manipulators and data imaging devices. The importance of portability and energy efficiency stipulated by prolonged periods of continues usage and necessity to take into consideration the external factors, aggravates the signal acquisition, such as patient movements, fatigue level and others [8]. The design with the individual signal-processing unit, obviously, requires several devices and additional elements (batteries, power management and connection modules, transmitters and receivers), which is impractical.

In this paper, the authors propose a solution of portable wireless modular platform for biological signals registration, with the set of features, sufficient to solve previously discussed problems and guarantee the quality of the data received. The key features of the developed system are:

- Capability to measure different biological and other signals with minimal additional modifications.
- Universal RS-485 interface to connect various sensors and additional equipment;
- Embedded onboard computer, capable for data processing and driving signal generation;
- Telemetry transmission features.

2. MATERIALS AND METHODS

This section describes the structural design of the proposed platform and proves the solutions and technical elements used. The following functional problems were taken into account during the development:

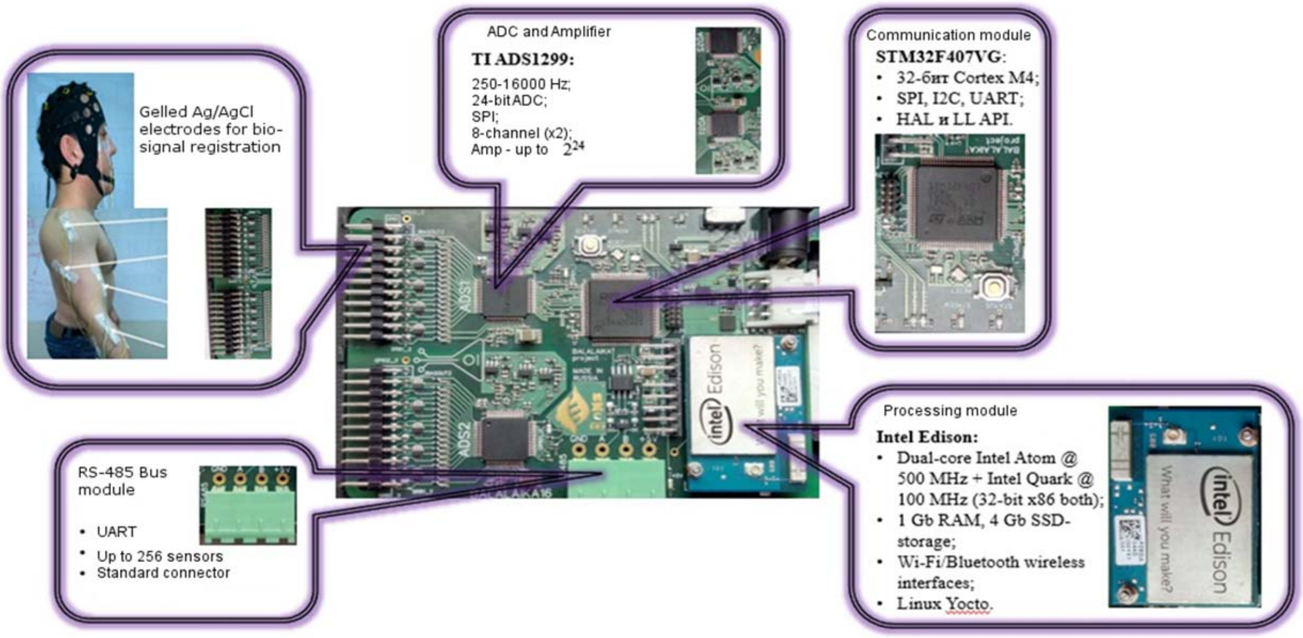
- Registration of potentials from the standard set of sensors, including EEG, EMG, EOG, to use the acquired data as the base for drive commands.
- Ability to use different external medical and supplemental sensors.
- Signal processing and drive command generation.
- Wireless transmitting of drive commands.
- Portability, endurance and safety factors.
- Ability to store the certain volume of data onboard.

Availability of different wire and wireless interfaces to connect sensors, external devices, driven equipment and data transmission for subsequent processing or storage.

Pic. 1 shows the schematic view of the developed device with main functional elements highlights and specifications. Printed circuit board housed in extruded plastic hull made with 3D printing, which permit to obtain the required specifications. The material of the hull is bio-compatible and safe for continuous use by humans during prolonged (i.e., days long) periods, which was proven by the test program.

Generally, the data flow passes through the functional modules in the following order:

1) Biopotentials acquisition using electrodes and transmitting to the amplifier without pre-amplification;
2) Amplification of the obtained signals with subsequent digitization [ADS1299];
3) Obtaining additional data from supplemental sensors [RS-485];
4) Packet generation for transmitting to processing unit and general system management [STM32F407VG];
5) Digital filtering and signal processing with subsequent wireless transmission to the external equipment, or, alternatively, onboard storage using Micro-SD card [Intel Edison].



Pic. 1. – Schematic view of the developed device.

The main focus of the paper is to describe the technical solutions used in the platform for signal registration and data processing. Because of that, we purposefully miss the stage of signal acquisition itself, so we will not discuss the questions of electrode placement and fixture, as well as the experiment set up. All these steps meets the requirements of the common practice [9] [10].

1) The module of signal acquisition

As the base for the signal acquisition module, the TI ADS1299 microchip was used. The main reason for that was its stable popularity among scientists and vast number of devises for biopotential registration build on its basis. For example, in [11] this chip was used as a reference to illustrate the influence of sampling rate and ADC on signal quality. Practical implementations of that chip includes such projects as open platform OpenBCI, Russian project NeuroIDSS, and single board EEG signal module from [12].

TI ADS1299 unifies the features of amplifier and analog-to-digital conversation of biopotentials. [13] Specifications of the given solution corresponds to best practice of the industry for microchip implementations: eight 24-bit delta-sigma ADC for the signal digitization, minimal noise (less than 1 mcV for 70 Hz frequency) and high CMRR (-110 dB) to keep low noise level, high sampling rate (up to 16 kHz) guarantees the wide range of sampling frequencies, embedded amplifier (up to 2^{24}) allows to register even the weakest signals. TI ADS1299's interfaces allow to cascade several microchips through daisy-chain connection for multichannel systems, using monopolar or bipolar connections. Besides, it has different programmable features and an energy saving mode.

TI ADS1299 meets all the requirements, given for non-invasive devices for registration of electro-physiological signals, like EEG, ECG and others, and high level of integrity and performance allows designing scalable measurement systems. The quality of the obtained data is practically equivalent to certified medical equipment [14].

The proposed device has 16 channels for electrophysiological signal registration, implemented with two TI ADS1299, connected via daisy-chain. Microcontroller software allows separate setting parameters for each microchip (sampling rate, amplification, etc.). Such model is scalable and allows designing any devices with any number of analog channels required in future.

2) RS-485 bus module

One of the key features of the proposed device is the capability to connect additional biometric and other sensors and supplementary devices. It became possible because of the original modular architecture: the central module can access the sensors through half-duplex EIA-485 bus, also known as RS-485. [15] Because of Unit Load conception, under certain circumstances, the number of connected devices can be considerably increased up to 256. UART protocol is used for data transmission.

RS-485 interface has specifications, sufficient to meet the requirements to data transfer from biological sensors, and standard electric features allows sensor development in a more unified way. Its implementation as the telemetry interface for space and military industry was offered in the section of future conception of metabolic monitoring systems in research [8]. To demonstrate the capabilities of the proposed platform to work with additional sensors we designed and tested several devices:

- Photoplethysmography sensor, made on Silicon Labs EFM32G210F128 microcontroller with ARM Cortex M3 core in QFN32 hull. MAX30102 chip from Maxim Integrated with infrared and red LEDs, photodiode and ADC was used as a sensor. Heart rate calculations were performed by embedded microcontroller with original software for discovering the peaks and R-R index. This way, all data were represented in processed form.
- Temperature sensor was made on Silicon Labs EFM32ZG108F32 chip with ARM Cortex M0 core in QFN24 hull. The sensor was built on TI TMP112 chip, specially designed for body temperature measurements.
- Movement sensor on the base of Silicon Labs EFM32G210F128 microcontroller with ARM Cortex M3 core in QFN32 hull. The sensor was designed on Bosh Sensortech BNO055 chip, with embedded accelerometer, gyroscope, magnetometer and energy-saving processor to process data in real time. It was used as the supplemental sensor for spatial orientation and movement algorithms.

3) The central module

The core of the proposed device is STM32F407VG microcontroller, built on 32-bit Cortex M4 core. This core modification is built on ARMv7-M, that differs from the standard ARMv7 in separate manner of transferring data and instructions. This model is actually a RISC processor with some special instruction support (Thumb and Thumb2) for bit operations with 16-bit numbers. The feature of M4 family is the DSP processing module for digital signal processing, to allow parallel calculations and speeding up some operations with data flows. This microcontroller also has letter F which means the module of real numbers. The computational power of STM32F407xx is 1.25 DMIPS/MHz and can be as high as 210 DMIPS, giving it a solid prize place among microcontrollers. In this case, the additional capacity means scalability and extension features for future implementations.

Cortex M4 is energy efficient enough to be the part of mobile devices with high endurance, equal to 8-bit and 16-bit competitors. Despite higher energy consuming, it is more effective in calculations, so it can show better performance per period. Besides, it has some energy saving features. [16] Additional DSP instructions and support of fast interruption (8-15 cycles for integer operations and 8-32 cycles for real operations) also improves real time processing capabilities of the processor and its energy efficiency. These features can be used effectively in future models of the device.

Interconnections between modules of the device were quite simple, as all required interfaces were already implemented on the microcontroller. It allowed limiting the number of external interface modules for additional sensors connection. So, TI ADS1299 connected by the SPI protocol, additional sensors on RS-485 bus connected via UART, as well as processing module based on Intel Edison. Battery management module bq27421-G1 connected via I2C. The software for the implementation of given interfaces was written with special drivers and API, that simplified the access to function remarkably. Software access to the interfaces allows easy tune of the functions by simple software upgrade.

4) The processing module

One of the main drawbacks of the commercially available devices is the absence of onboard processing unit. [17] Scientific research and industry devices are made for potentials registration solely, or designed for a well-defined limited task. This approach is valid for clinical or laboratory environment, with central task of evaluating the physical state of the patient, but for human-machine interaction such raw biometric and electrophysiological data can be used only as the source for drive command generation.

In contrast to OpenBCI and TMSi Porti 32, the proposed platform has embedded processing unit in the form of single board computer Intel Edison. Because of that, it is capable of complex data processing, and transmission of drive commands for external units. Intel Edison is a System-on-a-chip, equipped with dual core x86 Intel Atom (500 MHz) processor, single core x86 Intel Quark (100 MHz), 1 Gb of LPDDR3 POP RAM, 4 Gb eMMC flash-memory plus several communication modules (Wi-Fi, Bluetooth, Micro-SD slot). Such specifications gives the processing capacity better than in any type of microcontrollers. Power consumption of such device, designed for IoT (Internet of Things), is also quite low: 0.66 W (200 mA@3.3B) with communications off and 0.94 W (285 mA@3.3B) with Wi-Fi turned on.

An important factor to choose Intel Edison is the x86 architecture, with support of different sets of additional commands (for example, SSE2, SSE3, SSE4.1/4.2). After installation of the officially supported Intel Linux Yocto (the Linux system for embedded and mobile solutions, architecture independent), such single-board computer can run the Python code, imported from table systems.

External connections for Intel Edison board were based on Wi-Fi/Bluetooth module, built on Broadcom BCM43340. Two-band Wi-Fi (2.4/5 GHz, IEEE 802.11 a/b/g/n) and Bluetooth 4.0 supports connections to any external devices. As there are several interfaces for data storage and transmission (including USB 2.0 and SD memory card), additional modules are not necessary. Vast set of interfaces on Intel Edison board also allows miniaturization of the PCB.

3. RESULTS AND DISCUSSION

The proposed platform has been designed with the idea to meet the maximum number of requirements for laboratory and real life use both individually or as a part of the sets of sensors, data processing systems, data storage and transfer systems, biosignal driven devices, etc. The key advantages of the devices are:

1. The capability to use different sensors connected to several interfaces (the usage of EEG, EMG, EOG, PPG and temperature sensors was successfully demonstrated during tests). Short wire length from EEG electrodes to ADC, high quality of digital EEG signal, good S/N ratio puts the device into the category of scientific and laboratory equipment.
2. Small size and weight, portability, internal battery, wireless communication makes it wearable and suitable for E-health and monitoring programs.
3. High onboard signal processing capacity with simple and effective Python programming language. The trained neural net implemented in Python was used for classification, as well as for movement patterns extraction and drive command generation.
4. Durable and safe. Internal data storage and memory card allow temporary data storage in case of connection fault, internal battery ensures better endurance and a USB slot makes direct PC connection easy.
5. High degree of flexibility. All logical parts of the platform were implemented as the code and separated into modules that can be upgraded according to current requirements.

The main purpose of such devices is to manage different external equipment, data transfer and real time biosignal monitoring.

1) The task of generating drive command for external equipment (for example, upper extremity exoskeleton) has some complications, mainly because of the need to generate drive signals in real time and processing data from sensors in real environment and noisy conditions.
2) Data transfer for telemetry purposes includes the requirements to the quality of the signal, temporary storage in case of connection fault and ability to perform initial data processing onboard (for example, to discover critical condition of health).
3) Real time biosignal monitoring can be used both for the patients with high risk of critical condition and for prolonged monitoring (days and weeks) of the dynamics (for example, for metabolic monitoring for law enforcement, military and emergency personnel in action [8]).

Nowadays, a lot of different designs of signal registration devices and driven equipment are utilizing. It can be categorized based on functional purpose into several groups:

1. Scientific equipment for real time registration and research of biopotentials for prolonged periods, with feedback or external devices driving tasks under laboratory conditions ([18], [19], [20]).
2. Medical equipment, driven by commands based on biopotentials: different exoskeletons, neural or muscle stimulation systems, data imaging devices ([7], [21], [22], [23], [24], [25], [26]).
3. Data transfer equipment for monitoring condition and biopotentials of the patient for prolonged time for tele-medicine or E-Hhealth programs ([7], [8], [11], [22]).

For example, in research [19], which belongs to the first group, an opportunity of interconnection between mice cortex activity sensor and special "neuromorphic processor" has been studied during items movement tests.

Such studies become progressively more important, but require a lot of expensive equipment. The need to have a universal device, capable to register, digitize and transfer data from different biopotential sensors can hardly be overestimated.

In [18], it has been demonstrated the feasibility of an integrated neuroprosthesis combining a hybrid BMI, based on both cortical and muscle activity, with an exoskeleton and NMES for neurofeedback training via a virtual environment. This neuroprosthesis increased the ROM of wrist movement in chronic stroke patients with a severe impairment of an upper extremity. A hybrid system of exoskeleton and virtual reality was implemented in combination with neural stimulation. Obviously, a portable device, that can register biosignals and generate drive commands, can lead to a breakthrough for such hybrid systems. Moreover, for feedback closed loop systems like proposed in [26], it can become the best choice as it literally has all the parts of such system already embedded. The functional electrical stimulation alone or in combination with external mechanical device becomes more popular as rehabilitation, tremor suppression and assisting methods. That approach dictates more complex feedback signaling, spread between different channels, so single board computer device can be several times cheaper and convenient than regular bulky laboratory equipment.

Finally, a quite old research [8] describes the basic concept of a smart telemetry system for medical, prognostic and military purposes. The development of a universal portable device for biosignal registration, as well as for data storage, transmission, initial processing for prognostic and feedback systems is the core part of the concept.

Some of the authors of this paper also participated in developing and evaluating of neurodevice with same conception and showed effectiveness and appealing of such approach [27].

4. CONCLUSIONS

This paper describes a novel design of the platform for registration and processing of electrophysiological and biometric data, as well as its main features that make it useful for different research and medical tasks. Also, the feasibility was briefly evaluated, through comparison, for the range of applications, described in various research papers. The questions of construction, microchip selection, logical modules, software architecture were also covered. The proposed system can become one of the simplest and most convenient solutions for obtaining multimodal biosignals with high quality and is capable to proceed the obtained data for subsequent transmission to external devices or play a role of a telemetry tool with high processing capacity. In contrast with the traditional approaches, where phases of signal acquisition and data processing are separated and data pass through several devices, the proposed platform allows to integrate these features in one PCB, and, in fact, becomes the only intermediate link between human and external mechanical devices.

The next stage of the research will be dedicated to the evaluation of data processing capabilities onboard and the drive command generation module tests. The usage of trained artificial neural net for classification and movement pattern extraction was proposed, according to the best practices, but the effectiveness of command generation for proposed configuration is to be proved yet.

To demonstrate the technology and for experimental purposes, the external mechanic arm will be used as the driven device during different tests like moving, reaching, grasping, etc.

The proposed design can, obviously, become a cheaper and portable alternative for the scientific equipment and medical exoskeleton designs as it combines the best practices in the industry of wearable devices with laboratory grade signal acquisition and data processing capabilities.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Education and Science of the Russian Federation, grant RFMEFI57815X0140.

REFERENCES

1. Lebedev, M. "Brain-machine interfaces: an overview." *Translational Neuroscience*, 5(1) (2014): 99-110.
2. Poletti, Roberta, et al. "Diagnostic Tools: The Easier, the Better." The Breathless Heart. Springer International Publishing, 2017, pp. 219-234.
3. Banville, H., and T. H. Falk. "Recent advances and open challenges in hybrid brain-computer interfacing: a technological review of non-invasive human research." *Brain-Computer Interfaces*, 3(1) (2016): 9-46.
4. Kumari, Preeti, Lini Mathew, and Poonal Syal. "Increasing trend of wearables and multimodal interface for human activity monitoring: A review." *Biosensors and Bioelectronics*, 90 (2017): 298-307.
5. Hasan, Md Kamrul, et al. "Design and simulation of cost effective wireless EEG acquisition system for patient monitoring." Informatics, Electronics & Vision (ICIEV), 2014 International Conference on. IEEE, 2014.
6. Soh, Ping Jack, et al. "Wearable wireless health monitoring: Current developments, challenges, and future trends." *IEEE Microwave Magazine,* 16(4) (2015): 55-70.
7. Lay-Ekuakille, Aimé, and Subhas Chandra Mukhopadhyay. *Wearable and autonomous biomedical devices and systems for smart environment*. Springer, 2010.
8. Chen, Wei-Chen, et al. "An EEG analog front-end design with wireless communication module for a portable EEG monitoring system." Consumer Electronics-Berlin (ICCE-Berlin), 2015 IEEE 5th International Conference on. IEEE, 2015.
9. Niedermeyer, Ernst, and FH Lopes da Silva, eds. *Electroencephalography: basic principles, clinical applications, and related fields*. Lippincott Williams & Wilkins, 2005.
10. Láhoda, Frieder, Arno Ross, and Walter Issel. *EMG primer: a guide to practical electromyography and electroneurography*. Springer Science & Business Media, 2012.
11. Eren, Halit, and John G. Webster. *Telehealth and Mobile Health*. CRC Press, 2015.
12. Acharya, Deepshikha, Asha Rani, and Shivangi Agarwal. "EEG data acquisition circuit system Based on ADS1299EEG FE." *Reliability, Infocom Technologies and Optimization (ICRITO)(Trends and Future Directions), 2015 4th International Conference on*. IEEE, 2015.
13. Instruments, Texas. "Low-Noise, 8-Channel, 24-Bit Analog Front-End for Biopotential Measurements ADS1299"
14. Frey, Jérémy. "Comparison of an open-hardware electroencephalography amplifier with medical grade device in brain-computer interface applications." *arXiv preprint arXiv:1606.02438*, 2016.
15. Instruments, Texas. RS-422 and RS-485 Standards Overview and System Configurations, 2010. Date View May 31, 2017 http://www.ti.com/lit/an/slla070d/slla070d. pdf

16. Tsekoura, Ioanna, et al. "An evaluation of energy efficient microcontrollers." *Reconfigurable and Communication-Centric Systems-on-Chip (ReCoSoC), 2014 9th International Symposium on*. IEEE, 2014.
17. Blasco, Jorge, et al. "A Survey of Wearable Biometric Recognition Systems." *ACM Computing Surveys (CSUR)*, 49(3) (2016): 43.
18. Grimm, Florian, Georgios Naros, and Alireza Gharabaghi. "Closed-loop task difficulty adaptation during virtual reality reach-to-grasp training assisted with an exoskeleton for stroke rehabilitation." *Frontiers in Neuroscience*, 10 (2016).
19. Boi, Fabio, et al. "A bidirectional brain-machine interface featuring a neuromorphic hardware decoder." *Frontiers in Neuroscience,* 10 (2016).
20. Wright, James, et al. "A Review of Control Strategies in Closed-Loop Neuroprosthetic Systems." *Frontiers in Neuroscience*, 10 (2016).
21. López-Larraz, Eduardo, et al. "Control of an Ambulatory Exoskeleton with a Brain–Machine Interface for Spinal Cord Injury Gait Rehabilitation." *Frontiers in neuroscience,* 10 (2016).
22. Contreras-Vidal, Jose L., and Robert G. Grossman. "NeuroRex: A clinical neural interface roadmap for EEG-based brain machine interfaces to a lower body robotic exoskeleton." *Engineering in medicine and biology society (EMBC), 2013 35th annual international conference of the IEEE*. IEEE, 2013.
23. Bhagat, Nikunj A., et al. "Design and optimization of an EEG-based brain machine interface (BMI) to an upper-limb exoskeleton for stroke survivors." *Frontiers in neuroscience*, 10 (2016).
24. King, Christine E., et al. "The feasibility of a brain-computer interface functional electrical stimulation system for the restoration of overground walking after paraplegia." *Journal of neuroengineering and rehabilitation,* 12(1) (2015): 80.
25. Grimm, Florian, et al. "Hybrid neuroprosthesis for the upper limb: combining brain-controlled neuromuscular stimulation with a multi-joint arm exoskeleton." *Frontiers in Neuroscience,* 10 (2016).
26. Zbrzeski, Adeline, et al. "Bio-Inspired Controller on an FPGA Applied to Closed-Loop Diaphragmatic Stimulation." *Frontiers in Neuroscience*, 10 (2016).
27. Shusharina N. N. et al. Multifunctional Neurodevice for Recognition of Electrophysiological Signals and Data Transmission in an Exoskeleton Construction. *Biology and Medicine,* 8(6) (2016): 1.