The development of a BCI prototype based on the integration between NeuroSky Mindwave Mobile EEG headset, Matlab software environment and Arduino Nano 33 IoT board for controlling the movement of an experimental motorcycle

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Abstract.*The brain-computer interface (BCI) is a scientific field recognized by its outstanding significance covering especially biomedical engineering issues to offer thought-controlled assistive devices for people suffering from neurological diseases causing them neuromotor disabilities. However, the major achievements of functional assistive mechatronic systems were obtained in laboratories aimed for experimentation and research studies by using high-performance equipment at the expense of higher costs, cumbersome working principle and solid experience across multidisciplinary areas. This paper proposes an original prototype of a simple brain-computer interface application based on the integration between NeuroSkyMindwave Mobile headset, the Matlab software environment and the Arduino Nano 33 IoT development board along with the necessary electronic components. The aim of the BCI application is the achievement of the control of anexperimental motorcycle by using multiple voluntary eye-blinks detected across the electroencephalographic signal. According to the current scientific literature, there is no evidence of a similar approach to develop a brain-computer interface assistive system providing both cognitive training and enjoyable feedback that can help the user to regain independence and self-esteem. The main contribution of this paper is consisting of the Matlab software implementation of an algorithm for counting multiple voluntary eye-blinks and its integration with the library of functions necessary for the acquisition of the EEG signal from NeuroSky headset and the functions required to send commands aimed to control the motorcycle based on the Arduino Nano 33 IoT development board.*

Keywords:Brain-computer interface,EEG, NeuroSky, Eye-blink, Arduino.

Introduction

Although researchers are still struggling with the implementation of a complete solution to avoid all the technical challenges, as well as the handling of every neurological human characteristic and the enhancement of the entire user experience, the Brain-Computer Interface (BCI) is an enthralling multidisciplinary scientific field.Thus, numerous related papers covering various applications and studies have been

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published during the last tenyears (Zhang, K. et al. 2020).Its incredible potential is especially highlighted by enabling people with neuromotor disabilities to regain their independence and self-esteem.

The amazing potential of the BCI is emphasized by leveraging the advanced techniques of artificial intelligence to translate thoughts into actions or decipher the mental intentions of someone who cannot anymore move his/her own superior or inferior limbs due to awful physical suffering.

Therefore, the BCI aims to help people with neuromotor disabilities, possibly caused by stroke, spinal cord injuries, amyotrophic lateral sclerosis, tetraplegia, or any other accident resulting in the interruption of the neural pathway connecting the major brain areas with the peripheral nerves and muscles. The working principle of the BCI is starting with the mental intention (for example: the imagination of moving the arm) and ending with the real action (for example: the execution of the respective movement) that should be performed by an assistive mechatronic device.

This paper proposes a BCI application, developed in Matlab software environment, to achieve the integration between NeuroSkyMindwave Mobile second edition and Arduino Nano 33 IoT development board. Regarding the working principle underlying the BCI application presented in this paper, voluntary eye-blinking is used as an efficient control signal for enabling the movement of the motorcycle included by the Arduino Engineering Kit Rev 2.

The purpose of the BCI application described in this paper consists of providing an attractive training environment. Thus,a rich user experiencerefers to a person with neuromotor disabilities who has the opportunity to familiarize with a BCI system, to gather the necessary practical abilities by understanding its working principle and getting interactive feedback regarding the cognitive tasks he/she has performed. Therefore, not only that the disabled person can learn faster to execute voluntary eye-blinks, but also he/she can really enjoy the training process.

The original contribution brought by this paper consists in the implementation of the Matlab programming functions necessary for the development of the BCI application. Thus, it was successfully achieved the integration between three levels.The first level is given by the sequences aimed at achieving the communication between NeuroSky headset and personal computer. The second level is a novel algorithm necessary for counting voluntary eye-blinks.The third level consists of the sequences aimed at sending the corresponding commands to enable or disable the running of the servomotor and the DC motor, which allow the motorcycle movement. Moreover, the novelty of the current BCI application is highlighted by the new idea of combiningthe innovator potential of NeuroSkyMindwave Mobile second edition portable headset with the creative mechatronic device consisting of the motorcycle provided by the Arduino Engineering Kit Rev 2.

Literature review

The BCI research field includes various applications based on the monitoring and measurement of mental states (Al Balushi H.M. et al. 2019), such as attention,meditation, stress degree, excitement. Among the most simple, powerful and precise to achieve cognitive tasks, there should be mentioned the use of voluntary eye-blinks as control signals, the frequency based visual stimulation, called SSVEP (Steady State Visual Evoked Potential (Salvaro M. et al. 2020) and P300 evoked potential (Kim, M. et al. 2019).Thereare various directions regarding the development of applications in the BCI field.The researcher’s attention has focused on controlling different mechatronic assistive devices: wheelchair (Huang X. et al. 2020), robotic arm, robotic hand, mobile robot, home appliances (Nafea M. et al. 2018), smart TV (Kim, M. et al. 2019) and smartphone (Martínez-Cagigal V. et al. 2018). There is also a special interest in the virtual instruments used in communication: typing on a keyboardand changing the position of the cursor across the computer screen.Another appealing research is consisting of the cognitive training environments based on interactive simulations with 3D scenes and characters(Salvaro M. et al. 2020). BCI is a multidisciplinary research field, extending/involving the differentengineering areas:signal processing techniques, artificial intelligence,control systems, and computer science.

Thechallenges encountered by the BCI field researchers are related to technical issues caused by the massive, expensive and complex EEG equipment, the variable accuracy depending on the acquisition method (invasive or non-invasive), lower information transfer rate, and higher processing power due to complex mathematical computations. Nevertheless, according to the current scientific literature, functional and efficient experimental prototypes of BCI have been conceived by the integration between commercial headsets (such as NeuroSky, Emotiv and Muse) and development boards (such as Arduino, Raspberry Pi, NI myRIO, micro-BIT and ESP 8266).

Methodology

NeuroSkyMindwave Mobile EEG headset

NeuroSky is a successful Silicon Valley company, founded in 2004, which has proven its leadership regarding the development of accurate, affordable, and compact electroencephalogram (EEG) biosensors plus innovative brainwave algorithms.The most recent edition of Mindwave Mobile was launched in 2018. It was used atthe current research work thanks to its features: an ergonomic design, enhanced embedded technology of noise filtering, new EEG sensor chip – TGAT2, and advanced hardware to achieve higher accuracy of the acquired EEG signal. Also, it is provided the access to the output of various brainwave algorithms, for example, the eye blink detection, which is associated with a value between 0 and 255, so that it can result in a “stronger” or a “weaker” eye-blink. Taking into account the rapid development of simple BCI applications, the most recommended portable EEG headsets are those provided by NeuroSky, thanks to their advantages: the acquisition of raw EEG at 512 Hz sampling rate without any financial costs, the measurements of EEG rhythms characterized by different frequencies (delta, theta, low alpha, high alpha, low beta, high beta, low-gamma, and mid-gamma), the official library of functions, dedicated to the developers who are passionate by programming novel applications implemented by using different software environments (LabVIEW, Matlab, Python IDE, Arduino, Windows,and Unity).

Arduino Engineering Kit Rev 2

Thanks to the collaboration between Mathworks and Arduino, a versatile engineering kit was developed to provide engineering students with the necessary theoretical content (physics and math principles used in mechatronics), detailed instructions, a set of electronic components, assembly pieces, and software tools to enable an interactive learning process practically and enjoyably.They have the chance to implement three challenging technical projects: a drawing robot, a webcam controller rover, and a self-balancing motorcycle. The application presented in this paper involved the control of the experimental motorcycle (fig. no. 1) included by the Arduino Engineering Kit.

Figure no.1.The NeuroSkyMidwave Mobile headset (left) and the Arduino Motorcycle (right)

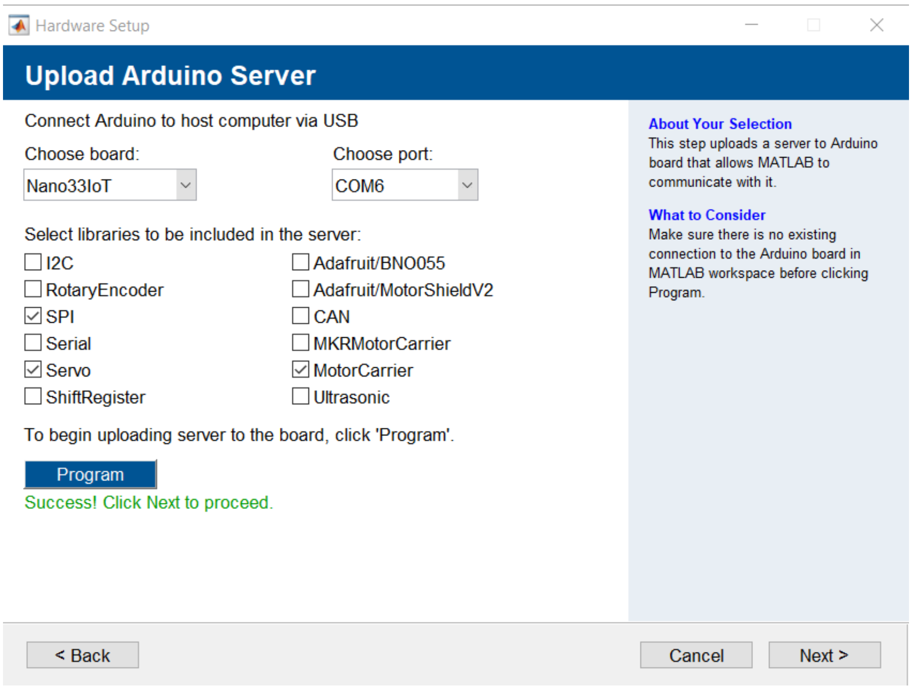
The hardware structure of the motorcycle consists of different electronic components. One of them is the Arduino Nano 33 IoT based on Atmel ARSAMW25 SoC and featured with Wi-Fi connectivity and a small form factor. Another electronic device is theArduino Nano Motor Carrier, an expansion board aimed to simplify the control of servos and DC motors connected to Arduino Nano 33 IOT. Also, the kit includes a standard micro servo for switching the movement direction (turn left or turn right) of the motorcycle, a large 12V DC motor with an encoder to rotate the inertia wheel, and a small 12V micro geared DC with encoder, which is featured with 100:1 gearbox for increasing the torque related to the movement of the rear wheel.

The proposed brain-computer interface application

This paper aims to demonstrate a solution for the integration between NeuroSkyMindwave Mobile headset second edition and Arduino Engineering Kit Rev 2 by implementing a novel Matlab program allowing the control based on the voluntary eye-blinks of the experimental motorcycle. This mechatronic device is connected to the personal computer by a serial interface and kept in a stationary position. Also,a support is used to avoid accidentally falling. The NeuroSky portable headset is connected to the personal computer by the Bluetooth interface.

This section explains both the Matlab programming sequences of the BCI application and the detailed steps that should be followed to run it properly. Beyond MATLAB software environment, there is necessary a Support Package for Arduino Hardware Add-On.

The first step is mandatory, and it is related to the setup and the configuration of the Arduino Hardware. Thus, the connection type (over USB) is chosen, the board type (Nano 33 IoT) is selected, the port number is set, the necessary functions libraries are checked. Then, the libraries can be uploaded to the Arduino board. This initial phase is triggered by a pop-up window that can be launched by typing ‘arduinosetup’ in the Matlab Command Window.



Upload Arduino Server

Connect Arduino to host computer via USB

Choose board: Nano33IoT

Choose port: COM6

Select libraries to be included in the server:

☐ I2C
☐ RotaryEncoder
☑ SPI
☐ Serial
☑ Servo
☐ ShiftRegister
☐ Adafruit/BNO055
☐ Adafruit/MotorShieldV2
☐ CAN
☐ MKRMotorCarrier
☑ MotorCarrier
☐ Ultrasonic

To begin uploading server to the board, click 'Program'.

Success! Click Next to proceed.

About Your Selection
This step uploads a server to Arduino board that allows MATLAB to communicate with it.

What to Consider
Make sure there is no existing connection to the Arduino board in MATLAB workspace before clicking Program.

Figure no. 2. The Setup and Configuration of Arduino Nano 33 IoT Setup

The second step corresponds to the implementation of Matlab code, starting with calling the functions that enable the commands sent to the DC motor and servo motor so that the motorcycle can be controlled. An Arduino object is used to enable the connection of Arduino hardware to Matlab so that the add-on libraries become available. They can be called to control the motors included by the motorcycle structure.Then, a motorCarrier object is used to enable the communication with the peripherals (DC motors and servo) connected to the Nano Motor Carrier. Further, a DC motor object is inserted into the Matlab code to allow the connection to the DC Motor, whose number is 1, on the Nano Motor Carrier. Moreover, the object functions – Start and Stop –are called to start and stop the DC motor rotation, taking into account the Speed property, which should be adjusted by assigning it a value between 0 and 1.

Likewise, a servo object is added into the Matlab code to enable the connection to a servo motor, whose number is 2, on the Nano Motor Carrier. Accordingly, object function writePosition is called to set the servo motor position to the specified value.

The third step consists of the functions aimed for the achievement of communication between NeuroSkyMindwave Mobile headset and the personal computer.

To get a successful connection between ThinkGear Chip of the NeuroSky headset and Matlab environment, the official library of functions (NeuroSky dedicated .dll for 64 bit or 32 bit versions) and the header file should be provided.

The voluntary eye-blink, characterized by a turbulence or a spike-wave across the electroencephalographic signal,can be identifiedas an increasing peak, followed by a decreasing peak of voltage. NeuroSkyThinkGear chip provides users a function for measuring the eye-blink amplitude, and it is compared with a threshold value, which should be initialized to a specific value, depending on each user profile. If the user gathers the necessary ability to execute accurate intentional eye-blinks, then he/she can use them as control signals to command an assistive biomechatronic device.

By implementing an algorithm to count the voluntary eye-blinks, the following commands for controlling the experimental motorcycle can be established:one eye-

blink for the Stop Command; two eye-blinks for Forward Command;three eye-blinks for Left Command;four eye-blinks to triggers the Right Command.
The algorithm allowing the counting of the voluntary eye-blinks is based on: initializing a numerical array with 4 elements, which are set to zero and using this array for storing the last four consecutive values of amplitudes defining the voluntary eye-blinks. The condition for detection of a voluntary eye-blink is described as it follows: the eye-blink strength should be higher than the threshold value, which is initially set. This condition is tested during the running of each function – Init, Forward, Left, Right – from the structure of the Matlabprogram.In the below paragraphs, it is referred to as the simple term: the condition.

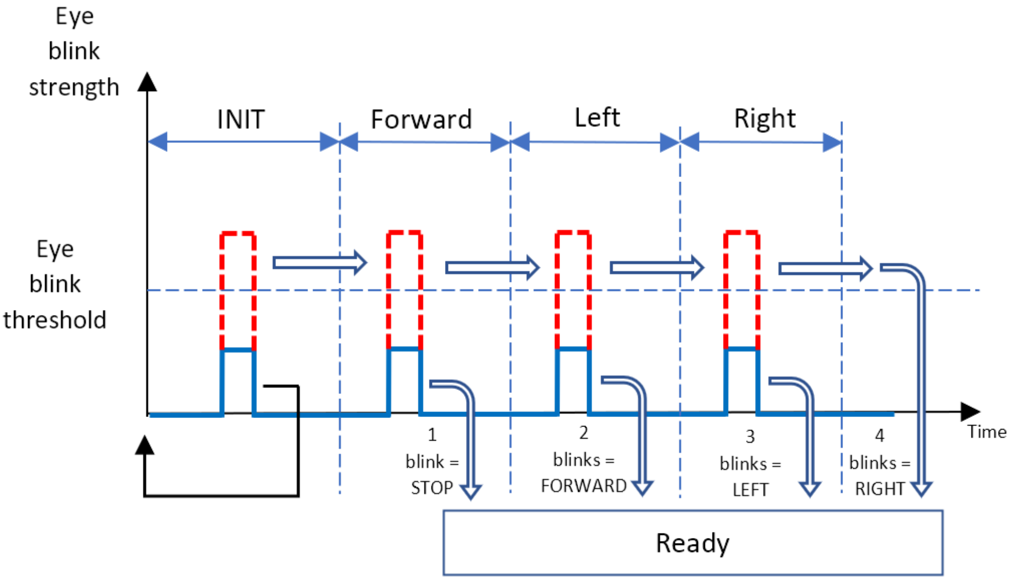


Figure no.3. The algorithm used for detection of the number of eye-blinks

If the condition is fulfilled during the execution of Init Function, then the first position of the array is assigned with the value of the eye-blink strength, which exceeds the given threshold, and the Forward function is called to be further executed. Otherwise, the first element of the array remains equal to zero and the Function Init should be executed again.
If the condition is fulfilled during the execution of Forward Function, then the second position of the array is assigned with the value of the eye-blink strength which exceeds the given threshold and the Left Function is called to be further executed. Otherwise, the second element of the array remains equal to zero, as it was previously initialized, and the Ready Function should be further executed.
If the condition is fulfilled during the execution of Left Function, then the third position of the array is assigned with the value of the eye-blink strength, which exceeds the given threshold, and the Right function is called to be further executed. Otherwise, the third element of the array remains equal to zero, as it was previously initialized, and the Ready Function should be further executed.
If the condition is fulfilled during the execution of Right Function, then the fourth position of the array is assigned with the value of the eye-blink strength, which exceeds the given threshold, and the Ready Function is called to be further executed, even though the condition is assessed with true or false result. Nevertheless, if the condition is not fulfilled, then the fourth element of the array remains equal to zero, as it was previously initialized.

According to the code instructions of the Ready Function, the eye-blink strength array is checked so that it should be edited by keeping only those elements that are different than zero. Therefore, by running the Find Function toward the eye-blink array, it will result inthe indexes or the position of only those elements that are different than zero. Next, it is checked the size, respectively the number of columns of the eye-blinks strength array. Further, the size of the array is equal to the number of voluntary eye-blinks that were executed by the user. By using a switch case statement, four different situations are taken into consideration, as it follows: array size = 1 (one voluntary eye-blink was detected = STOP command, set zero speed for the micro geared DC motor related to the rear wheel of the motorcycle, set servo motor to 90 degrees so that the front wheel will be straight forward-oriented), array size = 2 (two voluntary eye-blinks were executed = FORWARD command, maximum DC motor speed, servo motor at 90 degrees), array size = 3 (three voluntary eye-blinks were performed = LEFT command, maximum DC motor speed, servo motor at 60 degrees) and array size = 4 (four voluntary eye-blinks were achieved = RIGHT command, maximum DC motor speed, servo motor at 120 degrees).

After the execution of the corresponding code instructions, the Init Function is called to be further executed so that the entire algorithm is again followed and the continuous running of the Matlab application is enabled. According to the Init Function, the elements composing the eye-blink strength array are all initialized to zero so that the counting of the voluntary eye-blinks are reset. Each of the previously described functions – Init, Forward, Left, Right – is also calling the Read NeuroSky function, which allows the detection of the eye-blinks strength.

Function Read_NeuroSky is responsible for the acquisition of the value defining the eye-blink strength. By using 'callib' function, it is obtained the response related to the achievement of the correct output data from a series of functions specific to TGAT2 chip.Firstly, it is checked if a packet of NeuroSky data was read, by parsing it from the buffer and validating it with TG_Read_Packets() function.Secondly, by using TG_GetValueStatus function, it is checked if the packet of NeuroSky data returns interpreted and updated value for eye-blink strength. Thirdly, by calling TG_GetValue function, it is received the value of the eye-blink strength ranging from 0 to 255.

Results and Discussions

The BCI application proposed in this paper is based on a Matlab program necessary for counting the multiple eye-blinks so that there will be elicited commands for controlling the motorcycle. According to the algorithm that was previously described, the user should execute a number of strong eye-blinks (higher than the threshold) to select the command, followed by a weak eye-blink (lower than the threshold) to execute it.

The system was successfully tested. Eye-blinks strength is displayed, they are correctly counted, and the motors are controlled accordingly.

The BCI application is not intended to control a real motorcycle because the multiple eye-blinks cannot be fast enough to assure real-time control at high speeds. Moreover, the commands have to be refined to control the speed level and the angle for changing direction.At this stage,the system can be used for training purposes in correlating eye-blinks with different command types.

Conclusions

This paper proposes a BCI application for controlling the movement of an experimental motorcycle based on an Arduino Nano 33 IoT, by using a NeuroSkyMindwave Mobile

EEG headset. This application should help people with neuromotor disabilities to get trained regarding the execution of multiple voluntary eye-blinks by receiving immediate and enjoyable feedback.

The original contribution of this paper consists of the Matlab software implementation, including the integration of three different programming sequences. The first sequence is the configuration of the NeuroSky headset and the detection of the eye-blink strength. The second sequence is a novel algorithm for counting the multiple voluntary eye-blinks and the transmission of commands specific to Arduino Nano 33 IoT. The third sequence consists of running the servo and DC motors included by the motorcycle structure.

Regarding the future research directions, there are still necessary improvements to the BCI application by the integration of the library of functions specific to ThinkGear chip and the programming blocks from Simulink and Stateflow aimed to keep the experimental motorcycle in a balancing position as a consequence based on the inverted pendulum. The system will also be developed so that the user to control it to follow a specific route.

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