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A brain-computer interface based on the integration of NI myRIO development device and NeuroSky Mindwave headset

O A Rușanu[1], L Cristea[1], M C Luculescu[1] and P A Cotfas[2]

[1]Product Design, Mechatronics and Environment Department, *Transilvania* University of Brașov, Brașov, Romania
[2]Electronics and Computers Department, *Transilvania* University of Brașov, Brașov, Romania

E-mail: oana.rusanu@unitbv.ro

Abstract. This paper describes the development of a brain-computer interface system used for controlling a mobile robot by the eye-blinks strength. This project is aimed to help people with neuromotor disabilities who suffered from severe diseases causing them paralysis or the loss of speech. The proposed solution is related to the integration of NI myRIO platform with a NeuroSky Mindwave electroencephalographic headset in order to provide them an efficient, precise and robust communication channel with the outside environment. The eye-blinks are artefacts similar to the spikes that can be observed into the electroencephalographic signal. The difference between an intentional and a reflexive eye-blink is identified through the comparison of its strength to a given threshold parameter. Further, this paper describes a LabVIEW based application developed on the three programming levels from the NI myRIO (My Computer, Real-Time, FPGA Target) which enables controlling a mobile robot by different movement directions using the total number of voluntary eye-blinks. Therefore, the patient is able to use eye-blinks in order to send to the assistive device the following commands: stop – one eye-blink, go forward – two eye-blinks, go backward – three eye-blinks, turn left – four eye-blinks and turn right – five eye-blinks.

1. Introduction

Nowadays the brain-computer interface has become one of the most significant biomedical breakthroughs due to its amazing potential regarding the promise of positively changing the life of neuromotor disabled people who suffered severe diseases. These patients cannot communicate with the outside environment using their natural control channels such as peripheral nerves and muscle contraction. Accordingly, these persons lack the abilities of moving their limbs and speaking. The biopotentials generated within neurons are interpreted and translated into control signals for a computer, different mechatronic systems (a robotic arm, a wheelchair and an intelligent robot) and other devices like neuroprosthesis.

This cutting-edge technology encompasses advanced knowledge and hands-on experience in the following engineering and science research fields: signal processing algorithms, artificial intelligence, computer science, electronics, mechanics, neuroscience and psychology. Interdisciplinary research groups spread worldwide contributed a lot to the rapid evolution of the brain-computer interface domain of study.

Passionate and curious scientists worked together in order to take advantage of each other knowledge background. Thus they achieved some interesting applications that could help people with neuromotor disabilities to restore their independence, trust and joy of life. The scientific literature

[1][2][3] proves the development of really useful biomechatonic systems controlled only by analysing and processing the electroencephalographic signals which are followed by translating certain features into commands related to the movement of a smart wheelchair, a robot arm and the position of a cursor on the computer screen. As it is stated in the related research papers, these systems prove a very good performance and a high accuracy taking into account that the experiments were made only in laboratory conditions using massive equipment and even invasive procedures for brain signals acquisition.

Otherwise, hobbyists about science fiction gadgets have the chance to enjoy testing some portable electroencephalographic headsets that look appealing and seem to be professional. These futuristic devices are used not only for entertainment reasons but also for research. Young researchers worked on some projects [5][6][7][8][9][10][11] that involved the integration of such an affordable headset with a microcontroller based platform. Therefore, they developed reliable prototypes of mobile robots controlled by eye-blink strength or other types of applications which can be mentally controlled by the level of attention or meditation based on analysis the beta and alpha rhythms. On the educational websites, there are uploaded several Bachelor, Master or PhD papers [4][12] that show the considerable efforts invested by students to get usable and acceptable results that could be leveraged by suffering patients even with a non-invasive and a low-cost headset.

Further research should lead to a precise thought-control based assistive device, efficient filtering methods that could enable the avoidance of electroencephalographic signal noise and extraction of the relevant features of some cognitive patterns necessary in deciphering the real patient intention. The desire of achieving a complete embedded system that comprises both the software algorithms, hardware performance and electro-mechanical structure could be fulfilled by starting to improve the basic experiments that involved the use of accessible headsets in order to reach a more advanced level of brain-computer interface development and exceed the performance of the bulky systems whose functionality was tested in laboratory conditions.

This paper proposes a robust biomechatronic system relevant for the research on brain-computer interface field. Its working principle is simple so that it provides patients with disabilities a new way to communicate with their external environment. Thus they have the possibility of using eye-blink strength in order to control the directions movement of a mobile device that substitutes a motorized wheelchair. The released solution is based on the integration between NI myRIO system using LabVIEW programming environment and a NeuroSky headset with a wireless connection to a computer. This paper includes brief descriptions regarding the benefits offered by NI myRIO and the versatility of LabVIEW instruments delivered to engineers and the key features provided by NeuroSky headset.

2. Hardware system

The brain-computer interface application is consisting of the following hardware systems: NI myRIO development platform (figure 1a) and the NeuroSky Mindwave headset (figure 1c). This paper describes a mobile robot which can be controlled using the eye-blinks strength. The mobile robot (figure 1b) is built using a chassis with two wheels powered by two DC motors connected to a L298 driver, six ultrasonic sensors, a micro-servomotor, a Bluetooth module and other mechanical components.

NI myRIO system [18] is an embedded, compact, powerful device thanks to the Xilinx FPGA technology with 28.000 programmable gate arrays and the dual-core ARM Cortex A9 processor. It can be used to develop both LabVIEW based virtual instruments and other applications based on C/C++ programming language. Thanks to its auxiliary components, it offers the possibility to create complex biomechatronic systems. The advantages provided by NI myRIO are the following: high performance, LabVIEW programming, wireless connection, a large number of analog and digital inputs and outputs, interface with the NeuroSky Mindwave headset, Bluetooth module supported and efficient Real-Time processing.

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a) b) c)

Figure 1. Hardware system: a) NI myRIO development platform, b) mobile robot controlled using eye-blinks strength, c) NeuroSky Mindwave Mobile headset.

The NeuroSky Mindwave system [19][20] was launched in 2011 in U.S.A. It is a headset with an embedded biosensor aimed at the acquisition of the electroencephalographic signals from the frontal-central lobe called FP1. The e-sense algorithms provided by NeuroSky enable the fulfilment of the following functions: measuring the attention level, measuring the meditation level, detection of the eye-blink strength and the classification of the EEG rhythms into: delta (0-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz), gamma (30-50 Hz).

3. Software system

The software implementation of the brain-computer interface based application includes three levels of programming: My Computer, FPGA Target and Real Time. The My Computer level is aimed at LabVIEW based programming of the communication between NeuroSky Mindwave headset and computer. It is related to data acquisition and signals analysis in order to detect and count the successive voluntary eye-blinks strength that exceeds a given threshold. Further, the outputs of the My Computer -based application are the resulted commands transferred to the mobile robot. It substitutes an assistive device that can be controlled by different movement directions. Therefore, the FPGA Target is consisting of the decision-based algorithm regarding the enabling or disabling the digital lines used for switching the direction of rotation of the DC motors. The Real-Time application provides the communication between My Computer level and FPGA Target level. This task is achieved by using either the so-called shared variables or the NI VISA toolkit. If NI myRIO and computer are both connected to the same wireless router, then the shared variables are being read and written with certain boolean values in order to get the necessary commands (go forward, turn left, etc.) for controlling the mobile robot. Otherwise, if NI myRIO and computer are both connected using the Bluetooth communication protocol, then NI VISA toolkit is necessary to read or write strings corresponding to the user-defined commands (go backward, turn right etc.).

3.1. LabVIEW environment

This paper describes a series of software applications developed using LabVIEW [21] which is a graphical programming environment created by National Instruments Company. It intends to support engineers by providing them a powerful platform consisting of versatile and robust hardware devices, friendly programming approach and innovative solutions to the challenges encountered by various scientific fields such as: signal processing algorithms, image analysis techniques, measurements, control systems, interactive simulations, testing and automation procedures.

The development of LabVIEW based applications requires only a basic understanding of general programming concepts and a logical thinking to be able to translate the process of evolving from a novice to an experienced programmer by encouraging the implementation of design platforms such as: state machine, event handler, producer/consumer, queued message handler and functional global variable. Therefore, it is essential to gain enough LabVIEW programming experience to develop reusable, scalable and comprehensive virtual instruments.

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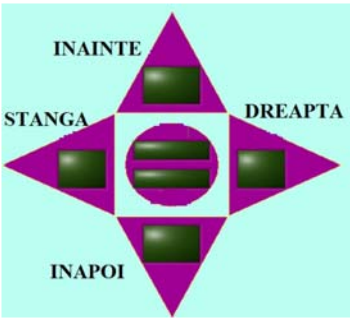
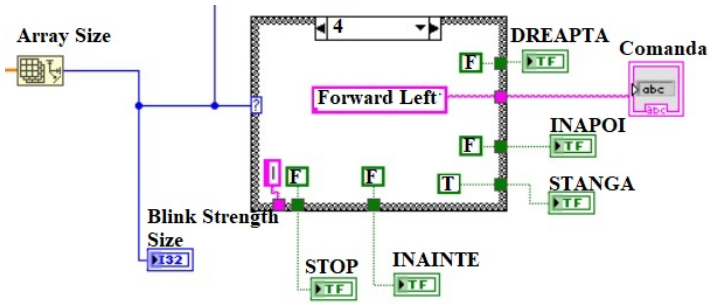
3.2. EEG signal acquisition and data analysis using LabVIEW – My Computer level

The first level of LabVIEW based system development is My Computer which provides the main user-interface (figure 2a) and fulfills the following functions: electroencephalographic (EEG) signal acquisition, data analysis and commands transfer in order to control the NI myRIO based robot.

The Block Diagram (figure 2b) is based on the state-machine design pattern which includes the following elements: a while loop, a case structure, a pair of shift registers and an enum constant. A state-machine paradigm is used to execute a series of states in a random order given by certain conditions or user inputs.



a)



b)

Figure 2. LabVIEW based application for mobile robot control using the eye-blinks detected in the EEG signal acquired from NeuroSky sensor: a) Front Panel, b) Block Diagram.

The EEG signal acquisition phase was achieved by calling specific subVIs provided by the LabVIEW based NeuroSky driver [16]. This is a ThinkGear .dll library [17] consisting of useful functions that allow running the following processes: the initial configuration of wireless communication between NeuroSky and computer, the assessment of the EEG signal quality, the possibility to enable or disable blink detection, the ability of reading the blink strength, the raw EEG data or its classification into specific EEG rhythms (alpha, beta, theta, delta, gamma) and safe closing or clearing the headset connections.

The EEG data analysis is related to a comparison operation between the acquired eye-blink strength value and a user-defined threshold parameter. Therefore, the LabVIEW algorithm aims to determine if the blink strength exceeds the given threshold. A true statement shows an intentional eye-blink. A false statement means a reflexive eye-blink.

The sequence of state-machine based Block Diagram is consisting of the following states: Init, Stop, Forward, Backward, Left, Right and Ready. Each state includes a case structure which handles the decision-based algorithm described above. Besides that, it was necessary to count how many eye-blinks the user achieved. This phase was implemented by using the functions related to the arrays of data. Thus, an array of double numeric data was initialized to zero, then all the successive eye-blink strength values that exceeded the threshold parameter were inserted into that array until this condition could not be fulfilled anymore. It resulted that the implemented algorithm counted only the intentional eye-blinks. Its number is given by the Array Size LabVIEW based function.

The working principle of the My Computer application that can be used by a disabled patient to control the mobile robot is described in detail in figure 3.

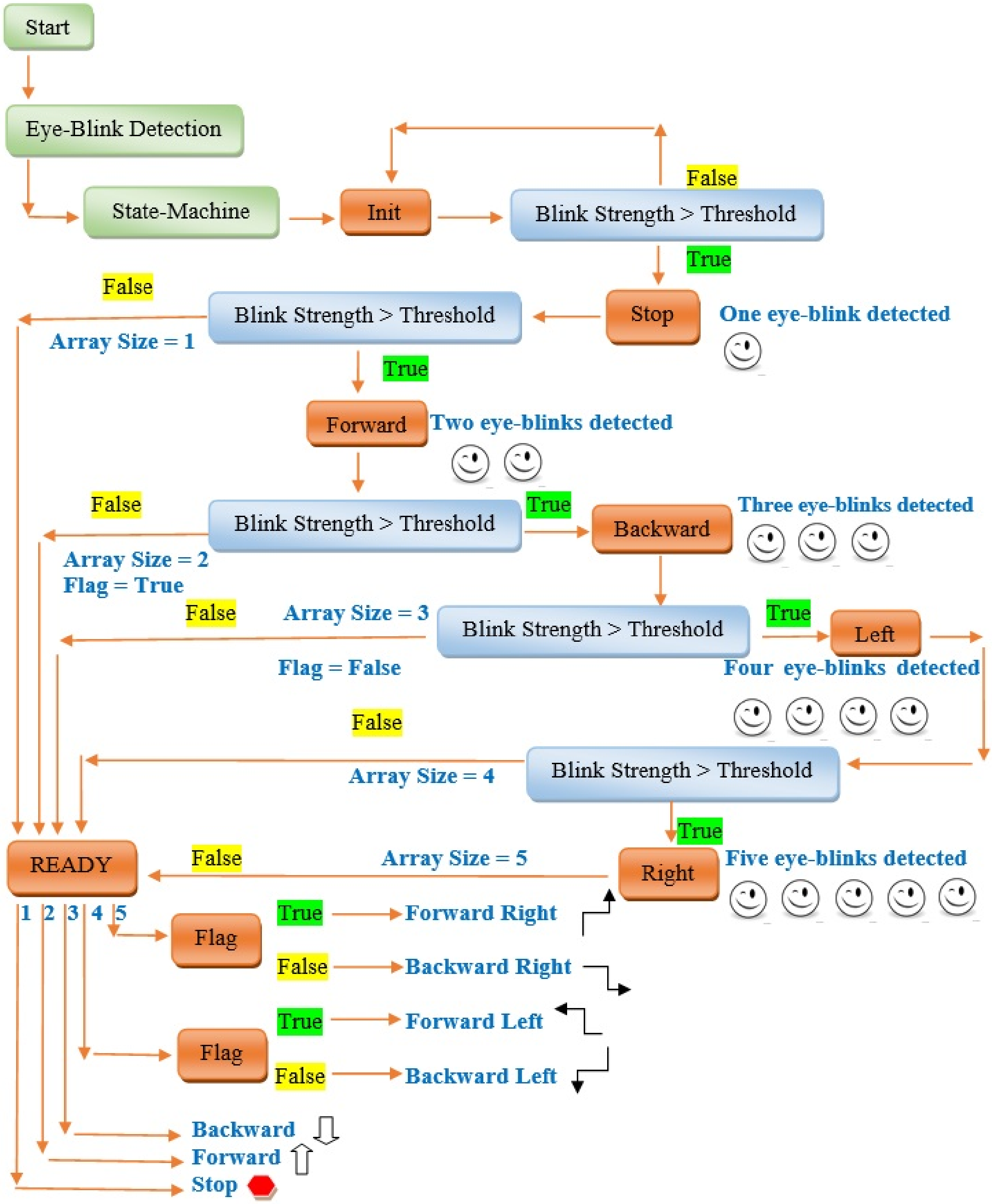
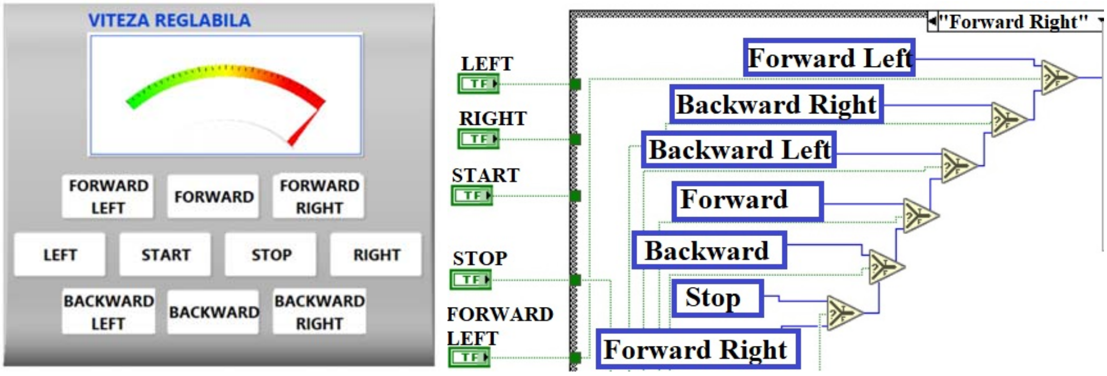


Figure 3. The algorithm of the LabVIEW based application enabling the communication between the computer and NeuroSky headset in order to detect and count the voluntary eye-blinks.

Stop command is sent when patients blink their eye once, then *Go forward* command is sent when two eye-blinks are detected and further *Go backward* command is transferred when three eye-blinks are counted. In a similar manner, *Turn left* and *Turn right* commands are executed as a result of identifying four eye-blinks and respectively, five eye-blinks. Switching the movement direction to the right or left is based on the previously given command: *Go forward* triggers only *Go forward left* or *Go forward right* and *Go backward* triggers only *Go backward left* or *Go backward right*.

3.3. The algorithm of controlling the movement of mobile robot – FPGA Target

The software implementation on FPGA Target (figure 4) level entails a series of LabVIEW programming sequences aiming to achieve the following major task: an algorithm necessary for the selection of the movement direction. This functionality is based on the following fundamental algorithm necessary for: adjusting the motors speed based on PWM signal (taking into account the explanations from [13]), reading the measured distance using data given by ultrasonic sensors (taking into account the explanations from [15]), and interactive control of a micro-servomotor (taking into account the explanations from [14]).



a) b)

Figure 4. LabVIEW based application developed on the FPGA Target level of the NI myRIO system: a) Front Panel, b) Block Diagram.

3.3.1. The algorithm implemented for the speed adjustment of motors based on the PWM signal.

A LabVIEW based virtual instrument aimed to run on FPGA Target was created on the Chassis level of the NI myRIO software project. The intention of the first algorithm is to enable access to the digital lines corresponding to motors connections and sending logical pulses (1 or 0) for turning them on or off. It was necessary to send intermediate values contained in the mentioned range (0 to 1) in order to result a variable motors speed. This intermediate logical level was based on the PWM signal generation. The LabVIEW virtual instrument should display a transition between the two fundamental levels (0 – low and 1- high) with a suitable frequency so that the human user could feel an increase or a decrease motors speed rotation.

3.3.2. The algorithm implemented for reading the distance measured by an ultrasonic sensor.

The NI myRIO based mobile robot controlled by eye-blink strength should be able to detect and avoid obstacles. The initial obstacle avoidance algorithm included a sequence of proper commands according to the previous movement direction of the mobile robot. However, the final solution supposed only a simple action: if an obstacle is detected on its direction of movement, then both motors get stalled so that the mobile robot executes the stop command.

Therefore, its mechatronic structure includes a series of six ultrasonic sensors used to read the distance between the current position of the robot and the closest obstacle. The LabVIEW virtual instrument from the FPGA Target returns the moment of time when the Echo signal was received on the corresponding digital line on the ultrasonic sensor. Previously, a pulse was sent to the digital line called Trigger. The calculation of the measured distance involved two sequences: the conversion of the time interval from microseconds into seconds and the applying of the mathematical formula: distance = sound speed * time interval. It was considered that the sound speed in the air is approximately 340 meters/second. The Block Diagram is consisting of two while loops, one implemented for Trigger pulse sending and the other for pulse width measurement which is, in fact, the moment of time (time of flight) when the Echo pulse was received.

3.3.3. The algorithm implemented for the interactive control of the servo-motor.
A micro-servomotor is used in order to extend the field of view that can be scanned by the ultrasonic sensor and perform an efficient obstacle detection. The LabVIEW virtual instrument enables the servo-motor control in a precise angular position. The algorithm is based on the PWM signal generation by periodically repeating a sequence of three states: enabling the digital line to whom the micro-servomotor is attached, waiting a variable time interval and disabling the previously mentioned digital line.

3.3.4. The algorithm implemented for switching between different movement directions.
The Block-Diagram is based on the state machine design pattern which handles the random transition between different states according to the movement directions of the mobile robot, for example: go forward, go backward, turn left, turn right and others. The user selection of the corresponding button triggers one of the previous mentioned state (table 1). The relevant command is sent over the Real-Time LabVIEW virtual instrument that should be deployed to the NI myRIO system.

Table 1. The next running state/command according to the user-selected button and the current state.

CURRENT STATE	BUTTON									
	Start	**Stop**	**Forward**	**Forward Left**	**Forward Right**	**Backward**	**Backward Left**	**Backward Right**	**Left**	**Right**
Init	Start	Stop	-	FWL	FWR	-	BWL	BWR	-	-
Start	-	-	FW	-	-	BW	-	-	-	-
Forward	-	Stop	-	FWL	FWR	BW	BWL	BWR	FWL	FWR
Backward	-	Stop	BW	FWL	FWR	-	BWL	BWR	BWL	BWR
Forward Left	-	Stop	FW	-	FWR	BW	BWL	BWR	-	-
Backward Left	-	Stop	FW	FWL	FWR	BW	-	BWR	-	-
Forward Right	-	Stop	FW	FWL	-	BW	BWL	BWR	-	-
Backward Right	-	Stop	FW	FWL	FWR	BW	BWL	-	-	-
Stop	-	-	FW	FWL	FWR	BW	BWL	BWR	-	-

In table 1 the following notations were used: FW – Forward, BW – Backward, FWL – Forward Left, FWR – Forward Right, BWL – Backward Left, BWR – Backward Right

The mobile robot has a chassis with two wheels that are actuated by two DC motors connected to a L298N driver. Both motors are connected to the A connector of the NI myRIO system so that the corresponding digital signals are the following: DIO1, DIO2, DIO3 and DIO4. These input lines are assigned with suitable boolean values True – T and False – F, according to the user-selected motors state that controls the movement direction of the mobile robot (table 2).

Table 2. The values assigned to digital lines of the Connector A from NI myRIO system in order to control the DC motors direction according to the given command.

Command	DIO1	DIO2	DIO3	DIO4	Description
Stop	F	F	F	F	Both motors are stalled.
Forward	T	F	T	F	Both motors rotate clockwise.
Backward	F	T	F	T	Both motors rotate counter-clockwise.
Forward Left	T	F	T	T	The right motor rotates clockwise. The left motor is stalled.
Forward Right	T	T	T	F	The left motor rotates clockwise. The right motor is stalled.
Backward Left	F	T	T	T	The right motor rotates counter-clockwise. The left motor is stalled.
Backward Right	T	T	F	T	The left motor rotates counter-clockwise. The right motor is stalled.

4. Conclusions

The paper highlights the integration between NI myRIO development platform and NeuroSky Mindwave electroencephalographic headset in order to enable the implementation of a brain-computer interface aimed to help people with neuromotor disabilities. They need a bio-mechatronic system able to provide them self-confidence, safety, comfort, independence and autonomy regarding the daily activities. The proposed solution is related to controlling a mobile robot using the voluntary eye-blinks which are artefacts in the electroencephalographic signal acquired from the NeuroSky sensor. This paper includes a detailed description of the decision-based algorithm necessary to count the voluntary eye-blinks so that the desired command be achieved. Such an application could allow the testing and simulation of the brain-computer interface based working principle. The proposed control strategy proved to be simple and precise so that it is based on the natural interaction between patient and the assistive device substituted by the mobile robot. Moreover, patients could benefit from a new training equipment in order to improve their ability of efficiently controlling a motorized wheelchair by using the eye-blink strength. Regarding the future work, the research is driven in the following directions: the development of an efficient obstacle avoidance algorithm, the substitution of the mobile robot with an assistive device (for example, a motorized wheelchair) and the implementation of advanced EEG signal processing methods in order to improve the accuracy of the commands sent by patients using their eye-blinks strength.

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