A Virtual Environment-based Training System for the Blind Wheelchair User through use of 3D Audio Supported by EEG

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Many difficulties are encountered by people with disabilities, especially when a diagnosis is made up of more than one dysfunction, as is the case of visually impaired wheelchair users. In fact, this scenario generates a degree of incapacity in terms of the performing of basic activities on the part of the wheelchair user. The treatment of disabled patients is performed in an individualized manner according to their particular clinical aspects. People with visual and motor disabilities are restricted in independent navigation. In this navigation scenario, there is a requirement for interaction, this requirement justifies the use of Virtual Reality (VR). In addition, locomotion needs to possess natural control, in order to be successfully incorporated. Based on such a condition, Electroencephalography (EEG) has shown great advances in the area of health, concerning spontaneous brain signals. This research demonstrates through experiment, the use of a wheelchair adapted with support of VR and EEG for the training of locomotion and individualized interaction of wheelchair users with visual impairment. The objective being to provide efficient interactions, thus allowing social inclusion of patients considered otherwise incapacitated. This project was based on the following criteria natural control, feedback, stimuli and safety. A multi-layer computer rehabilitation system was developed incorporating natural interaction supported by EEG, which activates the movements in the Virtual Environment and real wheelchair through adequately performed experiments. This research consists of elaborating a suitable approach for blind wheelchair user patients. The results demonstrated that the use of Virtual Reality with EEG signals has the potential for improving the quality of life and independence of blind wheelchair users.

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Abstract

Many difficulties are encountered by people with disabilities, especially when a diagnosis is made up of more than one dysfunction, as is the case of visually impaired wheelchair users. In fact, this scenario generates a degree of incapacity in terms of the performing of basic activities on the part of the wheelchair user. The treatment of disabled patients is performed in an individualized manner according to their particular clinical aspects. People with visual and motor disabilities are restricted in independent navigation. In this navigation scenario, there is a requirement for interaction, this requirement justifies the use of Virtual Reality (VR). In addition, locomotion needs to possess natural control, in order to be successfully incorporated. Based on such a condition, Electroencephalography (EEG) has shown great advances in the area of health, concerning spontaneous brain signals. This research demonstrates through experiment, the use of a wheelchair adapted with support of VR and EEG for the training of locomotion and individualized interaction of wheelchair users with visual impairment. The objective being to provide efficient interactions, thus allowing social inclusion of patients considered otherwise incapacitated. This project was based on the following criteria natural control, feedback, stimuli and safety. A multi-layer computer rehabilitation system was developed incorporating natural interaction supported by EEG, which activates the movements in the Virtual Environment and real wheelchair through adequately performed experiments. This research consists of elaborating a suitable approach for blind wheelchair user patients. The results demonstrated that the use of Virtual Reality with EEG signals has the potential for improving the quality of life and independence of blind wheelchair users.

1 Introduction

People with disabilities face a daily battle, as the lack of accessibility and social inclusion is still a big problem (Fiegenbaum, 2009) (Aguiar *et al.,* 2014). There currently exist a significant number of people with disabilities and therefore solutions that will help these people are constantly sought, whether for mobility, rehabilitation, communication or digital inclusion. In Brazil, there are still many structural issues in the area of therapy for the disabled. For example, the 2010 Census (Brasil, 2012) shows that 45,606,048 of Brazilians, 23.9% of the total population, have some kind of disability - visual, auditory, motor, mental or intellectual. Visual impairment had the highest incidence rate, affecting 18.6% of the population. Second is motor impairment, occurring in 7% of the population, followed by auditory in 5.10% and mental disabilities in 1.40% (Brasil, 2012).

The disability knowledge area offers categorical challenges in helping people with severe needs, and their impact on the right to come and go. This constitutional right is often violated due to the lack of accessibility

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(Silva, 2014). Especially when dealing with patients who have more than one significant disability. Those patients are classified as incapacitated for independent living. Motivated by this scenario, this work is about the difficulty of locomotion of the blind wheelchair user. This class of patients, by far, depends on the use of wheelchairs for the rest of their lives. In fact, individuals with multiple disabilities, on average, are shown to suffer greater exclusion from new technologies. Digital inclusion applications are particularly relevant in this group, allowing individuals to overcome some of the daily occurring barriers (Anagnostopoulos *et al.,* 2006). In general, physicians prescribe wheelchair equipment for patients with multiple disabilities (Costa, 2009). Although providing their main means of transport, it is important to note that these devices have to be adapted. The use of wheelchairs for daily activities appears as positive in terms of rehabilitation, since it improves the independence and autonomy of the population with severe motor limitation. However, much of this training is performed directly in a real wheelchair. On the other hand, studies show that the preparation of these patients, through computer-supported training, produces better conditioning, in contrast to actual device use. In this case, these computational systems need to be supported by a type of interface that provides the user with a more cognitive form of training. Among such, emphasis is placed upon Virtual Reality (Tori *et al.,* 2006). Virtual Reality can be visualized as a computational system used to create an artificial environment, in which the user has the impression not only of being inside this environment but also enabled, with the ability to navigate the same, interacting with its objects in an intuitive and natural way (Cardoso *et al.,* 2007). In fact, the VR is an interface that provides conditions of interaction with three-dimensional virtual environments with techniques that improve immersion and navigation properties. Additionally, studies demonstrate that creating a functional space for the tetraplegic individual through a computer system is favorable for the training of the wheelchair user (Fiore *et al.,* 2013). Diagnostics also demonstrate that the major challenges faced by people with visual impairment are orientation and mobility (Machado, 2003) and that a well-trained person can move around without assistance (Smith, 2001). Accordingly, through the above-mentioned studies and the long search for social inclusion, newly assisted technologies are being sought and developed (Berretta, 2015).

Locomotion interfaces, according to Patel and Vij (2012), have the potential to provide a feeling close to the standard of natural navigation, with an effective ability to develop navigational ability. One of the main functional interfaces is the BCI (Brain Computer Interface), which is a technique that aims at interpreting electrical signals from the cortical surface of the brain without going through nerves and muscles. This technique called Electroencephalography (EEG) is used to acquire brain signals to interact with the external environment through devices, seeking to interpret thoughts toward movements without the need for real movement (Costa *et al.,* 2012). Currently, the major VR systems for wheelchair training through brain waves do not support visually impaired wheelchair users (Folane *et al.,* 2016). Therefore, the synchronization between acquisition of the signal and the virtual environment presents itself as a challenge to be overcome (Bagacina *et al.,* 2014). This proposal behind this study is to therefore approach the development of a tool for training blind wheelchair users (Salatin *et al.,* 2016).

2 Related Work

The principal projects of automated BCI wheelchair design supported by EEG, put forward important characteristics for blind wheelchair users: Context, Interfaces, Control Sensors, User Feedback, Operating Environment, Safety Criteria and Qualitative & Subjective Assessments. The requirements presented have a strong cohesion to constitute an adequate solution for the blind wheelchair user patient. Therefore, the criteria are described as: Context: this consists of demonstrating the applicability scenario; Interface: how the communication of users between the physical and logical part occurs; Control Sensors: check which devices are used to control movements; Feedback to the user: determine how the reactive information will be presented; Functional Environment: mechanism of how procedures are performed; Safety Criteria: check tools and preventive measures; Objective and Subjective Evaluations: indicate the methods and type of analysis.

2.1 EEG Brain-Actuated Wheelchair System

Presents a prototype of an automatic navigation wheelchair developed in 2009 (fig. 1), new non-invasive brain actuated wheelchair that relies on a P300 neurophysiological protocol and automated navigation (Iturrate *et al.,* 2009). The subject faces a screen with a real-time virtual reconstruction of the scenario and concentrates on the area of the space to reach. This system utilized 3D interface using Virtual Reality integrated with brain-computer interface, which is a commercial gTec EEG system connected via USB to the onboard computer (Iturrate *et al.,* 2009).

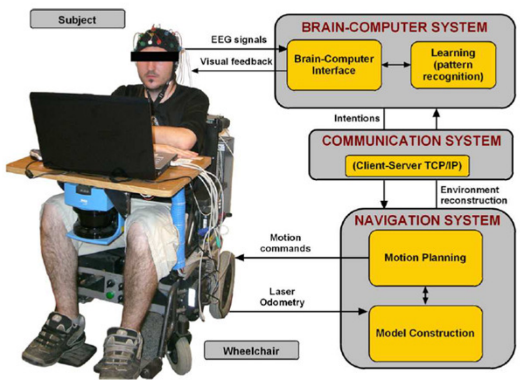

Fig. 1 – Synchronous EEG Brain-Actuated Wheelchair [17].

The experiment is based on a commercial electric robotic wheelchair with software architecture composed of a server and two integrated clients. The users perform the driving tasks and received feedback in the form of visual and physical interaction. One of the main difficulties of current navigation systems is to avoid the obstacles with appropriate safety margins.

2.2 Peripheral Control EEG

The Department of Electronic, Computer and Communications Engineering of Ateneo Manila University in Philippines built the BCI Application (2014) that enhanced device control and mobility. This is built on a 2D interface and NeuroHeadset NeuroSky BCI for interaction between users and simulations (Figure 2). Signal processing and data analysis was performed using MATLAB, The data gathered and processed for the project were EEG signals and facial artifacts derived from facial gestures and mental activities. One disadvantage is related to an inappropriate interface (Bagacina et al., 2014).

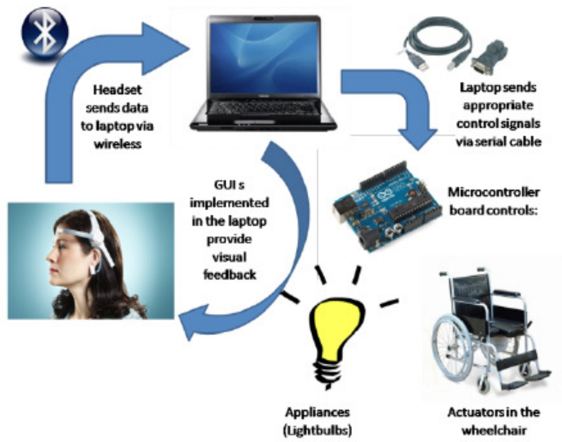

Fig.2 – Project Architecture Peripheral Control EEG (Bagacina et al., 2014).

2.3 Tactually-Evoked Wheelchair System

Kaufmann and Herweg (2015) focused their research on people with severe disabilities. The equipment utilized was comprised of eight tactile stimulators, (C2 tactors; Engineering Acoustic Inc., Casselberry, USA). The wheelchair Tactually Evoked System explored tactile ERP-BCI based online wheelchair control in a virtual environment (Kauffman *et al.,* 2015). Presented here is a 3D-model of a virtual building comprised of a single floor with four rooms and a corridor. It was used to achieve the simulated movement of the wheelchair through the building the virtual environment was connected to the BCI2000 via UDP. Participants controlled the wheelchair from a third person perspective according to figure 3.

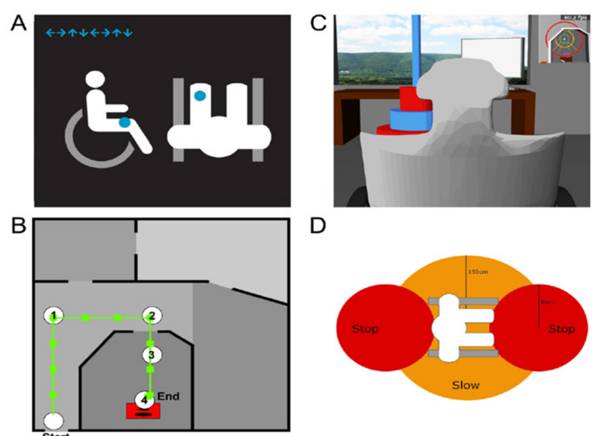

Fig. 3 – Wheelchair Tactually Evoked System (Kauffman *et al.,* 2015).

The advantage was a full 3D Virtual Environment. The main limitation of this study explored feasibility of the proposed BCI system are alarm collision and feedback perception for uses. The system is synchronous and not able to detect if a user desires to deliver a navigation command or perform any other task.

2.4 WI Control EEG

In this Project, EEG and eye-blinking signals through a Brain-computer interface based control for electric wheelchairs with wireless scheme is proposed (Lin *et al.,* 2012) according figure 4.

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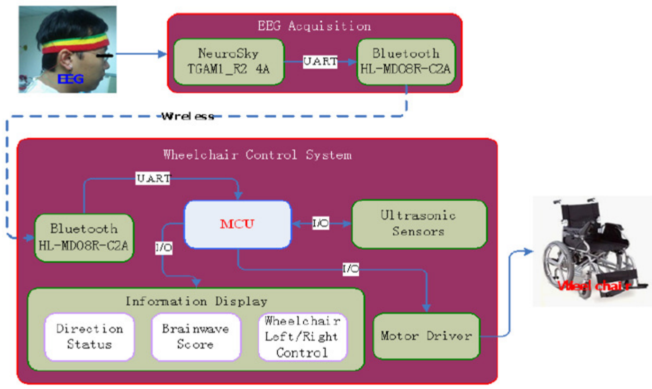

Fig. 4 –Wi Control EEG Flow (Lin *et al.,* 2012).

In a conventional wheelchair system, users require their hands to control the electric wheelchair. A simple electrode was used to capture EEG and eye-blinking signals from the forehead and these were transmitted to an electric wheelchair control system through a Bluetooth interface. The advantage of this project is its low cost and easy control with EEG and eye-blinking signals. The main disadvantages of this system are found in faults with Interface, Security Criteria and User Feedback.

2.5 Brain-Controlled Wheelchairs: A Robot Architecture

This study presented a shared control architecture that couples the intelligence and desires of the user with the precision of a powered wheelchair (Fig. 5). This was achieved through showing how four healthy subjects are able to master control of the wheelchair using an asynchronous motor–imagery based BCI protocol and how this results in a higher overall task performance, compared with alternative synchronous P300 approaches (Carlson *et al.,* 2013).

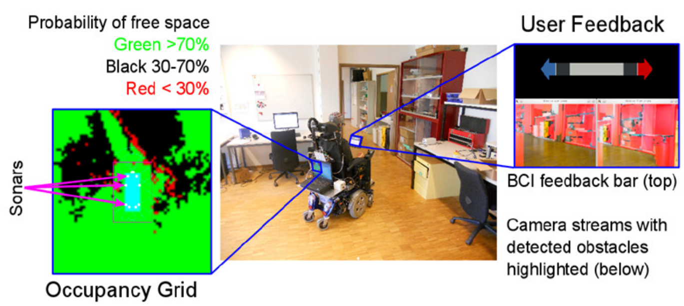

Fig. 5 – Brain-Controlled Wheelchairs: A Robot Architecture (Carlson *et al.,* 2013).

A big advantage the asynchronous BCI wheelchair brings, compared to alternative approaches like the P300, where the user is in continuous control of the wheelchair. This means that not only does the wheelchair follow natural trajectories, which are determined in real-time by the user. In the current implementation, the system has sonar sensors to avoid collision.

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2.6 Emotional BCI Control of a Smart Wheelchair

The incorporated BCI control system allows the user to select one of four commands to drive the wheelchair (Fattouth *et al.,* 2013). Once a command is selected, the control system executes the selected command and at the same time, monitors the emotional state of the user (Figure 6).

Fig. 6 – Smart Wheelchair Project (Fattouh *et al.,* 2013).

While the user is satisfied, the selected command continues to be executed and when the user is no longer satisfied, the control system will stop the wheelchair and ask the user to select another command. This project addressed the problem of integrating emotional state of the user in a brain computer interface system. In addition, using an emotional state of the user was considered as less effort orientated in choosing actions when conducting the wheelchair. The efficiency of the system was considered as being limited to the emotional state of the user.

2.7 Thought Controlled Wheelchair Using EEG Acquisition

The system is broadly divided into four blocks, the thought acquisition block, the thought transmission block, the thought processing block and the motor control block each of which aims at the acquisition of the EEG signal from user's scalp and processing it in order to control a wheelchair (Figure 7).

Fig. 7 – Thought Controlled Wheelchair Project (Kannan *et al.,* 2013).

The wheelchair controller has the functionality of controlling the direction and speed of the wheelchair based on the output bits obtained from the signal processing block (Kannan *et al.,* 2013). The focus of the

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project was the integration between EEG with microcontrollers for detecting brain signals for focusing the eye from left, right, up or down and use it to calculate the location of a cursor. The main bottleneck is absence of visual interface and feedback for the user.

2.8 A EEG Based Control System for an Intelligent Wheelchair

In 2013, National Engineering Research from Chongqing University (China) and Essex University (UK), developed a Brain Computer Interface to control an intelligent wheelchair based on EEG using Emotiv Epoc Neuroheadset (Figure 8) (LI *et al.,* 2013). The system realizes the motion control of the intelligent wheelchair through the subject`s motor imagery of the left hand, right hand, and legs.

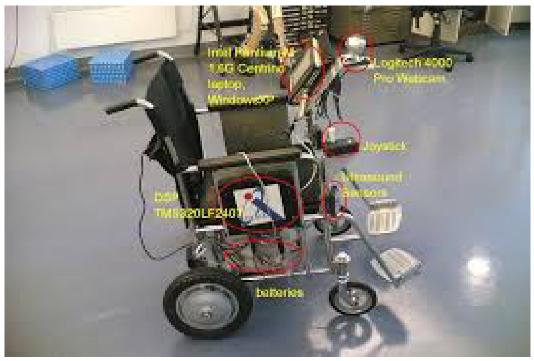

Fig. 8 – EEG Based Control System for an Intelligent Wheelchair (LI *et al.,* 2012)

Besides, the events pertaining to motor imagery are expressed in form of virtual movements as feedback to the system. The positive point is the control system feasibility, which has better stability than that of a basic practical application for an EEG control intelligent wheelchair. The cons of the system are a weak level of feedback for user and performance of autonomous navigation and obstacle avoidance among other functions.

2.9 Brain Based Control of Wheelchair

As a project for physically impaired users, this system is focused on receiving EEG signals, which are processed and then go on to perform control of the wheelchair. The classification of brain signals was performed using a Support Vector Machine (SVM) and neural networks (Figure 9).

Fig. 9 – Brain Based Control of Wheelchair (Abiyev *et al.,* 2015).

The EEG signals are measured through signal acquisition from the Emotiv Epoc Neuro-Headset, the project built a fully functional environment for a complete training procedure (Abiyev et al., 2015). The design of the control system check the emotional and muscular states of the user are evaluated for classification and control purposes. The design of the BCI was realized in order to conduct a brain controlled wheelchair using five mental activities of the user: Move Backward, Move Forward, Stop, Turn Left and Turn Right. For classification of EEG signals, SVM and neural networks, a 10 fold cross validation data set are used. These obtained high classification results.

2.10 Moving Towards a brain-controlled Wheelchair

In this project, a design for a non-invasive, EEG-based brain controlled wheelchair was developed for use by completely paralyzed or tetraplegic patients (Figure 10). The design includes signal processing algorithms and an interface for a powered wheelchair (Yazdani *et al.,* 2016).

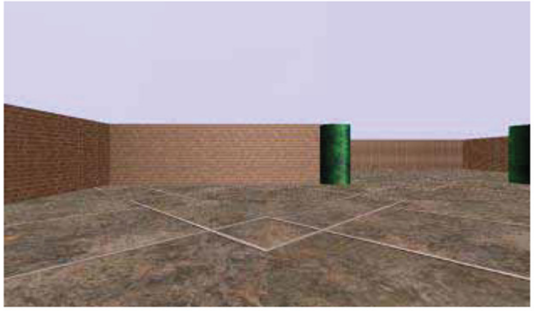

Fig. 10 – Moving towards a brain-controlled Wheelchair Prototype (Yazdani *et al.,* 2016)

In addition, a 3D virtual environment was implemented for training, evaluating and testing the system prior to establishing the wheelchair interface. Simulation of a virtual scenario replicating the real world gives subjects an opportunity to become familiar with operating the device prior to engaging the wheelchair.

The authors of this research project developed a 3D virtual wheelchair simulator according to Figure 10, to provide a safe and controlled environment for users to practice operating the Brain Computer Wheelchair before eventually engaging the real wheelchair.

2.11 A tetraplegic patient controls a wheelchair in VR

This project demonstrated that a tetraplegic patient, sitting in a wheelchair, could control his movements in VE by utilizing an asynchronous (self-paced) BCI, based on a single EEG recording (Figure 11). Whenever the band power exceeded the threshold a foot MI was detected. The simulation power of the VE ensured that the subject had the sense of being in the street and moving to the people; therefore the experiment was similar to a task in a real street. The reason for the missed avatars was the invisible communication sphere around the avatars, which was reported by the subject as the biggest disadvantage of this VE. So, it was not clear for the subject where the sphere started or ended, especially when the avatars were placed further away from the middle of the street and the sphere thus became very small (Leeb *et al.,* 2010).

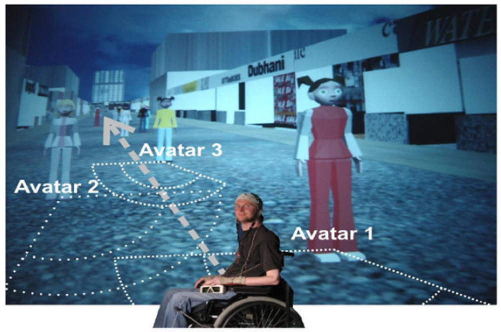

Fig. 11 – A tetraplegic patient controls a wheelchair in VR (Leeb *et al.,* 2010)

Another advantage here is that the simulation power of VEs can be used to create virtual prototypes of new navigation or control methods, and give potential users experience of such in a safe environment before they are ever physically constructed. In other words, VEs can be used for ergonomic design and evaluation. Unfortunately, immersion is not in an all-surrounding stereo environment with the freedom to move at will, which would give such persons access to experiences that may have been long forgotten.

2.12 EEG Based Brain Controlled Wheelchair for Physically Challenged People

The researcher Folane (2016) developed a Brain Computer Wheelchair for movement of a wheelchair based on Artificial Neural Network (ANN) algorithm using Murhythm signals that provide commands to the wheelchair (Figure 12). By using a wireless link between the head gear and computer, commands to control the wheelchair can be issued (Folane *et al.,* 2016).

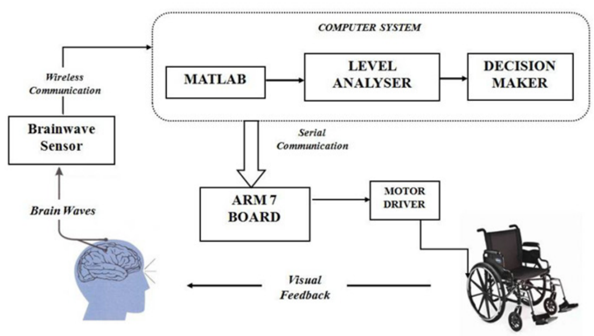

Fig. 12 – EEG Based Brain Controlled Wheelchair for Physically Challenged People (Folane *et al.,* 2016).

The advantage of this solution is based on the Computer System instituted in an analysis using Matlab for obtaining data from the sensor. The level of attention is compared to the reference level and generates a command for movement, this is achieved by utilizing a Neural Network algorithm for the decision making purpose. This system does not include a functional interface with safety criteria.

2.13 VR Wheelchair EEG Simulator

The work of Schuh (2013) developed a simulator for the training and learning in the use of a wheelchair controlled by a non-invasive ICC, using a low-cost Neurosky EEG device, which possessed the blink eye feature. The VR Wheelchair EEG design was made using Mindwave software with the e-Sense algorithm interacting with the VE developed in Unity3D with objects modeled in 3D Max. The control interface that the user uses to select available chair commands through the click of the mouse (Figure 13). This interface

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consists of 3 buttons that represent in order: rotate left, go forward, and rotate right. Each button is automatically highlighted by the application with an interval of 2 seconds, when then the highlight is changed to the next button, and so on (Schuh et al., 2013).

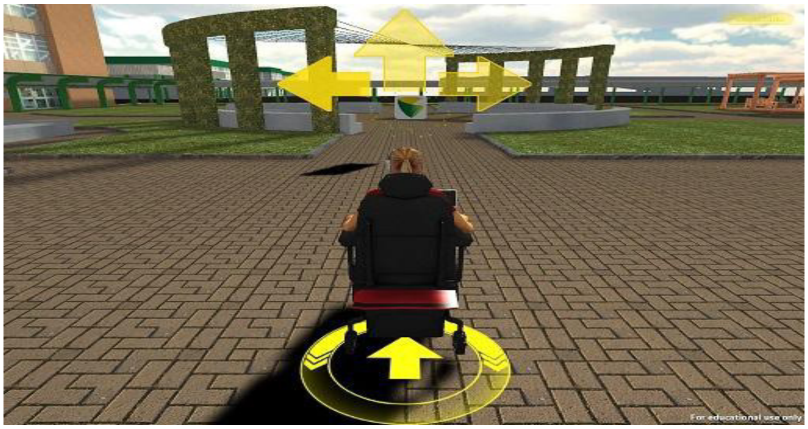

Fig. 13 – VR Wheelchair EEG Simulator (Schuh *et al.,* 2013).

2.14 EEG Brain Controlled Robotic Wheelchair Project

In this project, an EEG-based Brain controlled Wheelchair (Figure 14) was developed using BCI with the help of Neurosky technology.. The signals are processed by the ThinkGear module in MATLAB. The Level Analyzer Technique is performed on all the training signals and Alpha and Beta waves are extracted for controlling the wheelchair. The command signals are transmitted via RF medium (Rani *et al.,* 2015).

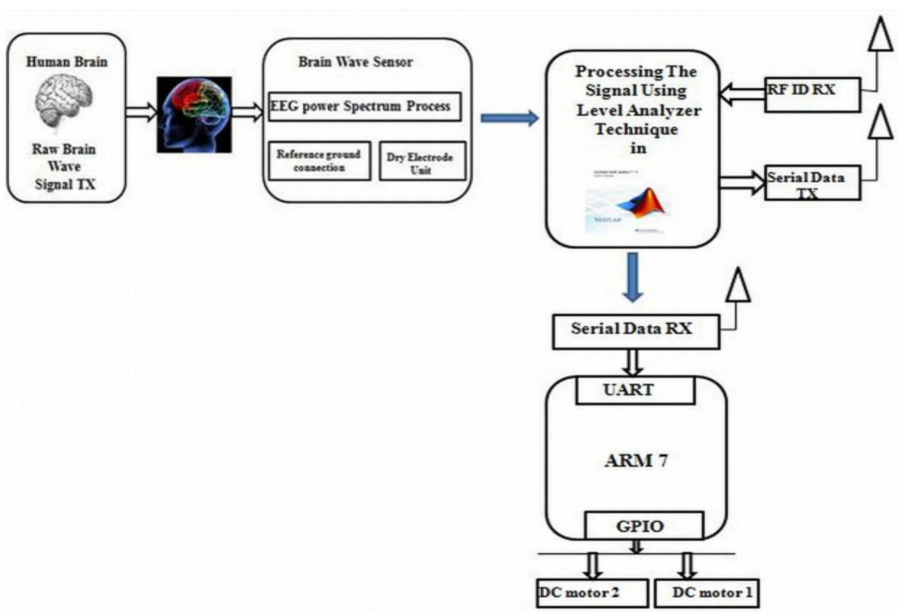

Fig. 14 – Overview of the system (Rani *et al.,* 2015).

The robotic module design consists of an ARM 7 Microprocessor coupled to a DC motor in order to perform the command. The Eye blinking strength and attention level were used to control the direction of the wheelchair. Two methods were proposed in the project. The attention signal was used for making a forward

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movement of the prototype and Eye blink strength was used for controlling the start/stop operations. The performance based on various metrics was analyzed. The level analyzer technique was implemented in signal processing and the wheelchair was controlled by the ARM7 Microprocessor. However, it requires improvement to the wheelchair for it to become more user-friendly. The wheelchair also needs to be further enhanced by removing artifacts and noise level for a more precise signal processing, and focus on additional improvements to the detection of any irregular eye blink so that, the wheelchair can be controlled accurately without any collision.

2.15 Smart Brain-Controlled Wheelchair and Devices Based On EEG at Low Cost

The project developed a wheelchair that can assist the disabled individual in their daily life to carry out tasks independently (Figure 15), and to bring this technique into the equipment, which can used by such individuals at home. The proposed system analyzes the brainwave signals and uses only a single electrode headset based on EEG sensors, which monitor the eye blinks, attention, and meditation.

These electrical waves will be sensed by the brain wave sensor and it will convert the raw data into packets and transmit these through wireless medium. The level analyzer unit (LAU) receives the brain wave raw data and then extracts and processes the signal using MATLAB. By using such it is possible to move a wheelchair in all directions (right, left, forward, backward) as well as control devices, through human thoughts both in attention and meditation mode (Akila *et al.,* 2015).

Fig. 15 –Wheelchair System Low Project Architect (Akila *et al.,* 2015).

This project efficiently built a robust architecture using blink eye to control the movements from a wheelchair. The most difficult task is to identify how the user can perform control without a user interface. Another important item is the appropriate environment for executing training, basically this system was designed with focus on users with motor deficiencies, but without minimum criteria for real users to perform tests with the fully activated solution.

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2.16 Comparison

One notes here that all projects are focused only on motor deficiency, leaving aside the visual dysfunction, which could be treated together, being necessary only to redefine the appropriate requirements for both disabilities. This comparison presents gaps that could be filled for new solutions according to demonstrate on Table 1.

Table 1 - EEG Wheelchair System Comparison

	User Interface	**EEG Signal Validation**	**System Feedback**	**Neuro Headset**
(Iturrate *et al.*, 2009)	3D	Visual	Visual	GsTec
(Bagacina *et al.,* 2014)	2D	Visual	Visual	Mindware
(Kauffman *et al.*, 2015)	RV	Tátil	Visual	-
(Lin *et al.*, 2012)	-	Facial	Move	Mindware
(Carlson *et al.,* 2013)	2D	Imagery	Visual	Emotiv
(Fattouh *et al.*, 2013)	2D	Motora	Visual	Emotiv
(Kannan *et al.,* 2013)	2D	Motora	Move	AD602
(Li *et al.*, 2013)	3D	Imagery	Move	Emotiv
(Abiyev *et al.,* 2015)	-	Facial	Move	Emotiv
(Yazdani *et al.*, 2010)	3D	Visual	Move	-
(Leeb *et al.,* 2010)	3D	Imaginary	Move	-
(Folane *et al.*, 2016)	-	Facial	Visual	Mindware
(Schun *et al.,* 2013)	3D	Facial	Visual	Mindware
(Rani *et al.,* 2015)	-	Facial	Visual	NeuroSky
(Akila *et al.,* 2015)	-	Facial	Visual	NeuroSky
(Souza et al., 2017)	**3D**	**Facial**	**Audio**	**Emotiv**

3 Overview

An overview of Disability and Rehabilitation highlights the importance of the brain signals (EEG) and Virtual Reality (VR).

3.1 Deficiency

The World Health Organization has developed a manual of relative classification and consequences of diseases. These include the occurrence of an abnormality, defect or loss of a limb, organ, tissue, or any other structure of the body, including mental functions. It represents the exteriorization of a pathological state, mirroring an organic disturbance or a disturbance in the organ. Consequently, an incapacity is a disability and/or a restriction resulting from a disability, opposite to the ability to perform an activity considered normal for a human being. This appears as a direct consequence or is the individual's response to a psychological, physical, sensory or other deficiency [53]. When a person has more than one deficiency, simultaneously, even without dependence relation (psychic, physical and sensory) and predominance of one deficiency over the other, it characterizes a multiple deficiency condition, according to Contreras & Valente (1993).

3.2 Rehabilitation

The term rehabilitation comes from the word habilitate, from the Latin habilitare, which means to render skilled, able, fit. The inclusion of the re-enable prefix has the sense of acquiring again a lost or diminished ability (Greve, 2007). In the medical area, the concept of rehabilitation always assumes a therapeutic connotation, as it seeks to return the individual with disability to an able condition (Lianza *et al.,* 2001). According to Lianza and Koda (2001), rehabilitation treatment is basically a programming of goals to be achieved and these should be directed to the reduction of disabilities and the prevention of disabilities.

For the same reasons, one must also identify the functional capacities of the individual, although the determinant conditions of the disabilities are extremely variable and depend on many factors such as age, culture level and educational level, socioeconomic conditions, etiology of the incapacitating disease, along with aspects of personality. Thus, the adequate diagnosis of the functional capacities makes it possible to increase the degree of independence and autonomy through a functional compensation work.

In a physical rehabilitation process, the physical (or motor) deficiency is characterized by a disturbance of the structure or function of the body, which interferes with the movement and/or the locomotion of the individual (Gorgatti *et al.,* 2003). It may involve weakness or limitation in muscle control (involuntary movements, lack of coordination or paralysis), limitations of sensations, joint problems or loss of limbs due to neurological, neuromuscular, orthopedic or congenital malformations (Correa, 2011). In addition to apparent physical-motor consequences, the physical disability marks the individual from a social, affective and communicative point of view, which sometimes are much larger lesions than readily perceived (Palma, 2010).

3.3 Brainwaves

A neuron consists of a cell body (also known as soma), dendrites and an axon (see figure 16). Based on the information dendrites receive from other neurons, the neuron now has to make a decision that is then sent to other dendrites of the neuron over the axon (Ward, 2010). Brain patterns form wave shapes that are commonly sinusoidal (Teplan, 2002).

Usually, these are measured from peak to peak and normally range from 0.5 to 100 μV in amplitude, which is about 100 times lower than ECG signals. By means of the Fourier transform power spectrum, the raw EEG signal is derived. In the power spectrum contribution of sine waves, different frequencies are visible. Although the spectrum is continuous, ranging from 0 Hz up to one half of a sampling frequency, the brain state of the individual may contribute to certain frequencies becoming more dominant. Brain waves have been categorized into four basic groups: beta (>13 Hz), alpha (8-13 Hz), theta (4-8 Hz) and delta (0.5-4 Hz) (Bickford, 1987).

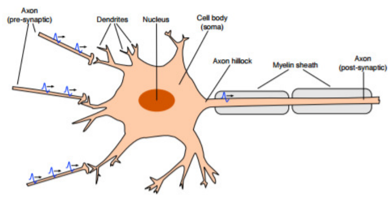

Fig. 16 – Neuron and Neural Structures (Ward, 2010)

3.4 Virtual Reality

Virtual Reality is an advanced interface for computational applications where the user can navigate and interact in real time in a computer-generated three-dimensional environment using multi-sensory devices providing the sensation of immersion (Tori *et al.,* 2006). The sensation of immersion occurs when the user receives sensorial stimulation through technological devices for visualization, perception, and control.

The Virtual Reality is based on three aspects: immersion, which is linked to the user's sense of presence in the Virtual Environment; Interaction, which is the ability to detect user actions and react instantly by modifying aspects of the application and involvement, which is the degree of motivation for engaging a person within a given activity. A Virtual Environment (VE) can be understood as a software system that creates the illusion of a world that does not exist in reality. This requires the combination of input (user interaction), computation (process simulation) and output (multi-sensory stimuli). The VE should contain virtual objects that will have certain associated attributes such as geometry, colors, textures, lighting, dynamic characteristics, physical constraints and acoustic attributes.

In general, virtual objects can be classified as static or dynamic, depending on the ability of each to move. In addition, the user must be able to navigate in three dimensions, that is, six degrees of freedom, in which, each degree applies the direction or rotation of the movement (Tori *et al.,* 2006). VE has been considered as the most natural form of interaction between man and machine, since it allows humans to use their senses, such as touch, hearing, and vision, in a similar way to the real world, to perform operations, sending and receiving information from the Computer (Kirner et al., 2008). The visually impaired have specific characteristics such as auditory, olfactory, gustatory and tactile systems, all of which are very important in their sensory experiences. The use of VR for aiding in visual impairment, which can establish new user interface paradigms, where individuals are not only in front of monitors, but rather interacting directly and can feel themselves as being within virtual environments, seeking sensorial interactions from the stimuli of the user. The sense of stimulus parts from user to the immersion, and as such, the interactions are performed.

3.5 Audio 3D

Audio 3D has the ability to position sounds all around a listener. The sounds are actually created by the loudspeakers, but the listener's perception is that the sounds come from arbitrary points in space.

This is similar to stereo panning in conventional stereo systems: sounds can be panned to locations between the two loudspeakers, creating virtual or "phantom" images of the sound where there is no loudspeaker. We use the term audio 3D to describe a much more sophisticated system to a more real or true 3D technology, the quality of the resulting sound is related to equipment and techniques of processing applied for immersive audio.

3.6 Requirements for blind wheelchair users

In general, each deficiency has pre-requisites for implementation of computational systems and experimental approaches for training and treatment solutions. One notes here that all projects are focused only one deficiency, leaving aside patients with more than one dysfunction, which could be treated together, being necessary only to redefine the appropriate requirements for both disabilities. Table 2, present the list of studies categorized with specific criteria required for each impairment, these projects presented important attention points.

Table 2 – Describe requirement for each deficiency

		Control	**User Feedback**	**Stimulus**	**Simulation**	**Audio 3D**	**Security**	**User Interface**
Motor Deficiency	(DING et. al.,2008)		✓	✓				
	(PALMOM, et. al., 2011)			✓	✓			
	(FIORE et.al 2013)	✓						
	(ALBELLARD et. al., 2012)		✓		✓			
	(CARLSON *et al.*, 1994)	✓			✓		✓	
Visual Deficiency	(RUI et. al.,2016)		✓			✓		
	(ALM et. al., 1998)				✓			✓
	(CHEEIN et.al 2011)			✓		✓		✓
	(MULLONI et. al., 2012)		✓			✓		
	(LOKUGE *et al.*, 2014)				✓			
Rehabilitati on	(RODRIGUEZ et. al.,2015)			✓	✓			
	(MAVER, et. al., 2000)		✓	✓	✓			✓
	(NINISS et. al., 2006)				✓			
	(HARRISON *et al.*, 2012)				✓		✓	✓

According to investigations into rehabilitation of visual impairment and motor deficiency, the approach for building a training solution for blind wheelchair users, identified functional requirements for each in compensatory approaches. Table 2 describe fundamental aspects for develop a solution to blind wheelchair users. The following seven criteria can be used to classify the level of treatment for patients/users.

- ***Control:*** determine the behavior by limiting the level and intensity.
- ***User Feedback:*** Reaction to particular actions (Visual, Sensorial or Audio).
- ***Stimulus:*** Use of sensory resources of patients, such as movement, hearing, and perception.
- ***Simulation Environment:*** imitation of the operation of a real-world process.
- ***Audio 3D:*** ability to position sounds all around a listener.
- ***Criteria Security:*** items for protection.
- ***User Interface:*** Interaction with software and machine.

4 Case Study

The patient is 33 years old, suffered a car accident on returning home after a day's work. He was diagnosed with cranial polytrauma in the presence of a loss of encephalic mass in part of the parietal lobe (Figure 17).

Fig. 17 – Blind Wheelchair User – Patient voluntary

Consequently, speech loss, neck movements down and vision completely compromised. The only means of communication with the patient is through blinking, in order to answer the questions, the stimuli of the eyes was interrelated into the understanding, therefore, interaction is made with others through the blinking of the eyes and facial expressions.

4.1 System Prototype

In this research project (Figure 18), a virtual environment for locomotion training for blind wheelchair users was developed, using hardware, software and computational techniques to improve interaction and inclusion of the patient. There are several types of research on the design, navigation, and evaluation of the use of the wheelchair, but there is no research of a virtual environment adapted for wheelchair users with visual impairment integrated with EEG (Rodriguez, 2015). For this adaptation, it is necessary to investigate the requirements for the construction of the prototype, according to Grant (2004), the architectures are derived from the main components as Visual Simulation, Physical Simulation and Control (Ayas *et al.,* 2015).

Fig. 18 – Overview Virtual Brainy Chair

The proposal of this work promotes a pre-training on the bed, and as this advances, it change to being performed on top of the wheelchair. The Visual Simulation consists of providing a simple or complex model depending on what is most appropriate, thus providing criteria and applying the necessary techniques to the prototype.

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One of the main features of this item is the Visual Interface with the 3D Audio implementation. But they are composed of several other items such as Virtual Reality, manipulation, navigation, real sense of control, stimuli, adaptability and Feedback (Ding *et al.,* 2007).

4.2 Architecture

The architecture was designed in layers to interact in a synchronous way so that each module can communicate independently to send or receive information. Basically, the wheelchair has been adapted to receive the batteries for powering the motors, motor control boards, notebook and the EMOTIV EPOC device.

The architecture is divided into three layers (Figure 19): Hardware Layer, Emotiv Epoc API and User Interface. In the first layer, hardware architecture, are the devices responsible for capturing, acquiring and executing commands for movements. The second Emotiv Epoc API layer performs the processing of captured raw EEG signals.

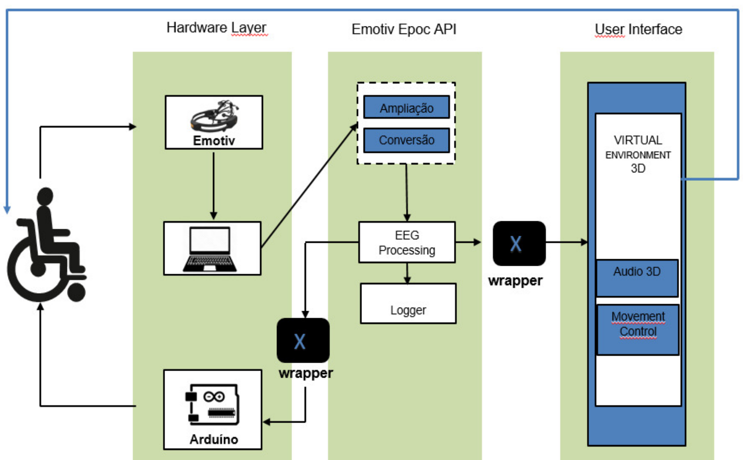

Fig. 19 – Virtual Brainy Chair Architecture

There is a sub-level with a wrapper, for communication with the Arduino micro controller, which has the logic to feed (force) and performs the locomotion activities next to the motor for wheelchair movements to occur.

The connector receives the information generated by the user to drive the motors located simultaneously in the lower right and left hand side of the wheelchair, defining the speed and direction of rotation of the motor.

The User Interface layer, is where the control for movements and application of the Techniques of Audio 3D is implemented, so that the actions in the virtual environment are reproduced. The integrations of these 3 layers formed a single block, the project is composed of 3 primary axes: 1) EEG capture; 2) Classification & Sending of Commands; 3) Replicate movement in the VE and in the wheelchair. An avatar was modeled to represent the user Virtual Environment.

In addition, the Logitech Surround Sound Speakers Z506 delivers 75 watts of power with 3D stereo and multiple inputs was implemented, as shown in Figure 20. The architecture was designed in layers to interact

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in a synchronous way, so that each module can communicate independently for the sending or receiving of information (figure 20).

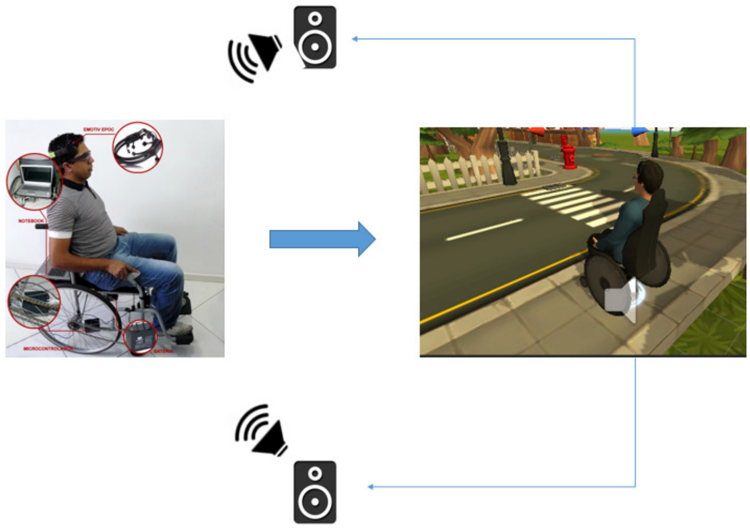

Fig. 20 – Functional Architecture.

4.3 *Virtual Environment*

The Virtual Environment was designed for the training of blind wheelchair users in the process of locomotion using a virtual wheelchair using the brain signals as a control mechanism supported through the Emotiv Epoc neuroheadset. Navigation takes place firstly through 3D sound orientation to indicate what will be the course and the movement to follow, so the user must perform a facial expression, in order that the required movement occurs. This project was modeled using the use of Engine Unity 3D. To do so, it was necessary to use all the features of the tool including scripting and multimedia functions to enrich VE scenes. In addition, 3D elements of the Unity 3D engine asset store were used for the complete creation of the virtual environment according to Fig. 21.

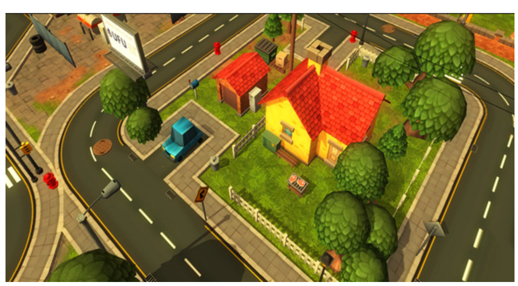

Fig. 21 – General bird's-eye view of the virtual environment.

The training sessions were designed to be conducted on public roads or sidewalks around the house, with obstacles and interactions to simulate locomotion. The movements are guided by 3D sound instructions to the patient and triggered by the brain signals based on the facial expressions and then by means of a wheelchair avatar using the wheelchair in the Virtual Environment, according to Figure 22.

After training, the total area of the virtual environment can be explored for free wheelchair navigation. To complement the 3D environment, the 3D Audio component was developed for the elements and the camera, the audio listener component, which will fetch all objects that have audio source enabled.

The movement projects a straight line and identifies each object according to the approach of the movement and the advancement of the displacement with the wheelchair avatar. Then the nearest speaker is fired, thus improving immersion in the virtual environment.

Fig. 22 – 3D model of patient in the virtual environment

A demonstration of this feature can be observed in Fig. 22, where the avatar is seen with the Unity 3D audio feature in the development mode.

4.4 Facial Expression and Movements

This section demonstrates how the application uses the expressive detection to control the movements made by the user wearing the Emotiv headset. The solution developed will translate Expressiv Emotiv Epoc API results into commands to move the virtual avatar and wheelchair (Table 3).

Table 3 - Commands based on facial expressions

Action	**Facial Expression**
Forward	Blink (2x)
Backward	Raised eyebrows (2x)
Right	Look right (2X)
Left	Look left (2X)
Stop	Clenched teeth (2x)

5 Experiments

The Brainy Virtual Chair project aims at enabling the user to move independently in the Virtual environment, with the purpose of going around the house along the sidewalk, as shown in figure 23.

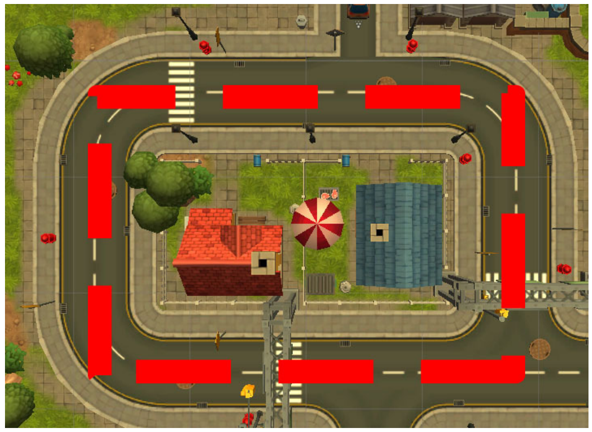

Fig. 23 – Route in Virtual Environment.

The experiment was performed with a two-stage blind patient: # 1) in bed (Figure 24); # 2) Wheelchairs (Figure 25). The Virtual Environment is used in both situations, using 3D sound techniques. To evaluate the performance of the system and verify if the patient is able to perform the training, sessions are performed in the virtual environment, accompanied by a health professional.

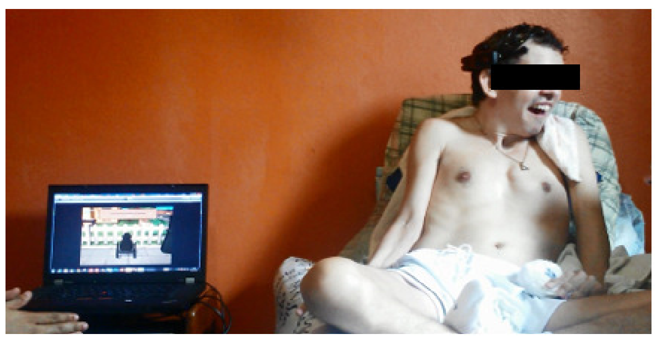

Fig. 24 – Simulation in progress, with patient on bed.

The patient will move through the virtual environment using EMOTIV EPOC, making the facial expressions as described in Table III. In this first part of the session, the circuit is activated with the patient on the bed, and soon after completion, the user initiates phase 2 of the training with the wheelchair. All procedures were followed to protect the patient's physical and mental well-being. In Fig. 24, the patient is shown prepared to begin the training with the wheelchair, and then beginning the use of the wheelchair.

Fig. 25 – Patient preparing for start a trial session

The patient is positioned in the wheelchair with a safety strap (Figure 25), the physiological data such as temperature, pressure and heart rate are checked. Then the virtual environment is started, the avatar is presented with written instructions and 3D Audio as shown in Figure 26.

Fig. 26 – Initial screen for virtual training

The main character of the virtual environment is the patient (Fig. 26), an avatar with a physiognomy close to that of the patient is used to generate greater realism for the physiotherapist. The implemented movements are: front, back, right, left and stop.

At the end of the experiment, the experience gained was evaluated in order to collect information on: Virtual environment, wheelchair adapted with EEG and Learning. It should be noted that the results were collected from the patient, physician and physiotherapist involved in the research.

6 Results and Discussions

This section presents an analysis of the experiments, aiming to demonstrate the feasibility of the approaches proposed in this prototype. The analysis includes the following aspects: use of the Virtual Environment with brainwaves, validation of navigational ability and movement control, and employability of the prototype as a training tool.

The work is qualitative, characterized as a descriptive study with empirical basis, systematic observation being used as a data collection instrument, based on (Clemente, 2014), which had a male patient with thirty-four years old.

The experiment began by measuring the communication time between the collection of brain waves to the movement represented in the virtual environment, and the wheelchair performance with assessment from patient.

6.1 EEG Wheelchair Interactions

The integration of EEGs in wheelchair control aims to reach a high-level of data related to usability, this in order to compare the interface BCI interaction allowing for satisfactory control and experience. Table 4, demonstrates that Emotiv presents a false positive for detection (Error 5%) for detections of facial representation, against 2% for Emotiv API, this result, however, does not compromise the experiment, as each movement can be validated by a visually validated facial expression by the professionals who accompany the training. Another important point was to balance the system to align the times of each component and thus provide a synchronism to replicate the movement in a natural way. A determining factor was the identification of the type of control for each component to implement feedback in 3D audio format.

Table 4 - EEG wheelchair interactions

	Time needed for signal capture [s]	Errors or Faults for execution (%)	System Control/Feedback
Emotiv Epoc	1 Sec	5%	External
API	0.5 Sec	2 %	Dynamic
Virtual Environment	3 Sec	1 %	Forcing
Wheelchair & Arduino	5 Sec	0.1 %	Robotic

To accomplish usability inspections and classification of the EEG interactions and the wheelchair, it became necessary to perform several specialized tests for accompaniment, with tests directed to the performance of the developed prototype. The concern was the simple efficacy and correctness of the movements, along with the validation by medical professionals.

6.2 *Virtual Environment*

The virtual environment presented several modifications during the pre-established conceptions, but for such a comparison two tests were carried out contemplating the virtual environment and the wheelchair in moments using only the virtual environment and another using the virtual environment plus the wheelchair (Table 5).

Table 5 – Results of Sessions (trials)

Trials	EEG Classified Correctely	Using Real Wheelchair	Average Time Need (min)	Number of Colisions (VE)	Interventions for Instructions	Errors of system/patient	Moviments Accuracy (%)
Prototype #1 – Initial Tests							
#1) Trial (Session 1)	57%	No	21 min	43	18	1 / 9	61%
#2) Trial (Session 1)	63%	Yes	25 min	57	8	1 / 6	65%
Prototype #2 – Included more instructions							
#3) Trial (Session 2)	84%	No	18 min	24	2	0 / 1	82%
#4) Trial (Session 2)	87%	Yes	17 min	16	3	1 / 2	85%

In the first session we noted that the patient had a low level of correct EEG classification due to the lack of step-by-step instructions to guide each movement in a more detailed way. For this reason it was evidenced that they had approximately 62% accuracy level for the required level of assertiveness. Trial #2 presented better results especially due to a better implementation of Interactive Audio instruction commands in the virtual environment, especially for the execution time of the activities. These are indicators that there has been an evolution, that is, a learning in the interaction process.

6.3 *Patient & Doctor Results*

The vital signs were considered, where it was possible to use these as an instrument to measure the impact on the patient's emotional and physical factors. According to the results of the physiological data, those readings taken after the training sessions show an increase in the vital signs of the patient according table 6.

Table 6 - Vital signs collected during trials

	Session #1	Session #2
Before Session		
Temperature	36°C	36.1°C
Heart Rate	78	86
Blood Pressure	13 / 9	12 / 9
After Session		
Temperature	36.4°C	36.5°C
Heart Rate	93	104
Blood Pressure	13 / 9	14 / 10

During the experiment, the AF3, F3, F7, F4, T7 and T8 channels were the ones with the highest activity and represented that these are responsible for the reasoning and control of movements, as shown on Table 6.

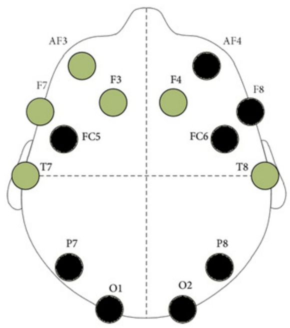

Fig. 27 – Mapped EEG signals with more intensity

Therefore, we have verified that channels AF3, F3, F7, F4, T7 and T8 should always be used for EEG solutions for blind wheelchair users, according to that mapped on figure 27. By recording average brain waves, we can verify this intensity across the EEG channels AF3, F3, F7, F4, T7 and T8 (Fig. 28).

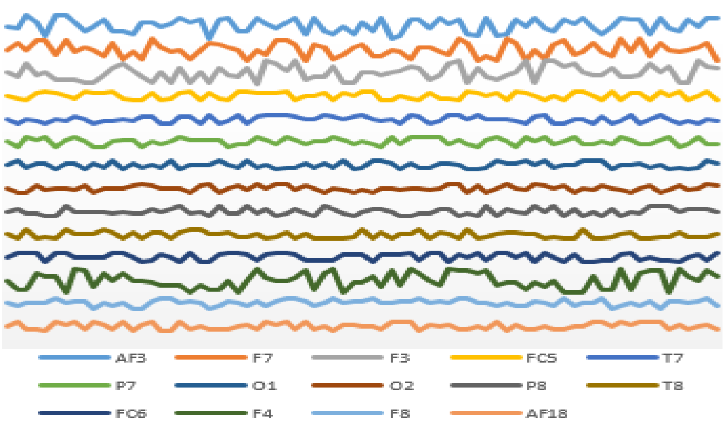

Fig. 28 – Average Recorded EEG per Patient

The checklist technique was used to document the evaluations, through a questionnaire to verify patient and physician satisfaction, using subjective methods. Figure 29 shows the level of patient and physician satisfaction. The experiments were performed in 2 sessions, taking place sequentially in periods of 40 days each session. The level of control and the sense of presence along with the effectiveness of the prototype are all found in the results of Table 5.

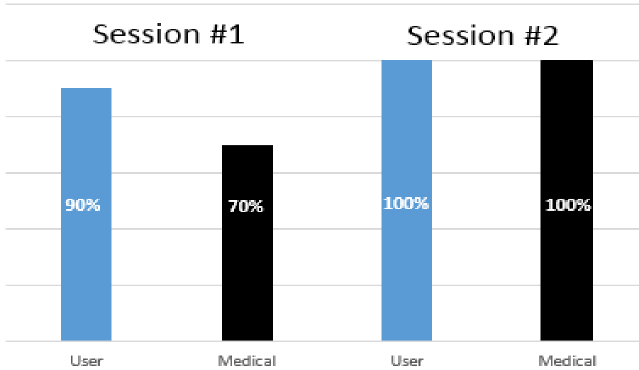

Fig. 29 – Level of satisfaction per experiment

In the first experiment a lower satisfaction percentage was seen, as here was a failure in mapping the instructions by audio.

7 Conclusion

In this work, a computational system was developed involving hardware, software, and computational techniques, in order to improve integration in the training of visually impaired wheelchair users. One goal was to extend the proposal for helping blind wheelchair patients at various levels to move more autonomously and independently. In the case study evaluated, it was demonstrated that the patient was able to test the tool and perform clinical practices. The test subject was still able to walk through pre-defined actions through use of the wheelchair and reproduce the actions trained in the virtual environment. This result shows that blind disabled people with varying degrees of injury can navigate independently with the help of appropriate rehabilitation tools and approaches, promoting accessibility and social inclusion, and using a tool built on specific special needs carriers adopting a multimodal architecture and specific tools that stimulate natural interaction, such as the use of Virtual Reality associated with audio resources and EEG. One of the main advantages of the use of VR for the blind wheelchair user is that it allows for the implementation of 3D audio techniques promoting a better immersion in the VE and provides the function of visual validation of movements by the technical professionals responsible for the session. Regarding the use of electroencephalography (EEG), the blind wheelchair user does not have downward neck movements as well as blindness generating incapacity to perform activities. Through use of EEG, it was possible to recover the function of controlling the movements of locomotion, through the adapted wheelchair using the brain signals. EEG technology is really important, as it reaches a level of patient neglected by conventional treatments.

In terms of usability, the patient learned to move around the virtual environment. Therefore, it is concluded that it is appropriate for educational purposes, without requiring the learning of a non-standard approach. It has also been demonstrated that the learning process can be more easily coupled with a safe and pleasant patient experience. By midway through the integration of the movement activities, associated with the capture and processing of brain signals, various potentialities and limitations of the brain/computer interfaces were demonstrated. The solution was well accepted by the patient and natural movements provided real navigation, which facilitated learning. The great differential of this work was the development of computational techniques, specifically, in patients who are wheelchair-bound and visually impaired. In general, these individuals in a majority of cases are not easily included in society. However, the tests were instrumental in demonstrating that there is a possibility of developing learning and allowing their social inclusion. The potential of this system, although still possessing reduced accessibility to these devices, was verified. In fact, incorporating brain-computer interfaces into the day-to-day lives of these people can mean their integration into society in ways that are not currently possible. The study demonstrated that with the training sessions, the patient showed satisfactory improvements of functional abilities in the margin of 10%, in addition, the results show that this class of patient can experience lasting gains, including memorization and speed of reasoning. Given the limitations of this study regarding the equipment used and sample size, as well as circumstances pertinent to the processing conditions of the data obtained, questions pertaining to the relevance of the findings may still be common. Despite this, it is believed that the research proves valid as justification of one of the most growing practices in current rehabilitation processes. In addition, the work indicates possibilities for sensor-motor integration. In this way, the Virtual Brainy Chair can be indicated in the aid of the training of disabled wheelchair patients, and consequently, contribute to the improvement of their quality of life.

8 Ethical Approval

The University Federal of Uberlandia granted Ethical approval to carry out the study within its facilities (Ref: CAAE: 68117717.0.0000.5152)

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