An accelerometer-based human computer interface driving an alternative communication system

MARIANO, D.T.G., FREITAS A.M., LUIZ, L.M.D., SILVA, A.N., PIERRE P., NAVES, E.L.M.

Abstract **– People with severe motor disabilities present reduction or absence of motor control. However, in different stages of these conditions, some people can perform voluntary movements of low amplitude. This paper presents the development of an Human Computer Interface – HCI – for controlling an augmented and alternative communication system. The device consists of an accelerometer to capture voluntary movements performed by users who have restricted movement such as patients with amyotrophic lateral sclerosis. The sensitivity of the device is calibrated according to the amplitude of the dynamic action executed by the user, allowing the placement of the sensor in different body regions, for which the use has some level of motor control. The system was tested successfully in healthy subjects suggesting that the accelerometer can be used in patients with motor disabilities.**

Keywords—Assistive Technology, Augmented and alternative communication, Accelerometer, Human Computer Interface, Motor disabilities

I. INTRODUCTION

In 2001, World Health Organization created an International Classification of Functionality, Incapacity and Health (ICF) which comprehends functionality and incapacity of a person as a dynamic interaction between health states (diseases, perturbations, bruises, trauma and others) and contextual aspects (personal and environmental elements). According to the Brazilian census by IBGE (Brazilian Institute of Geography and Statistics), in 2010 there were 46.7 million of persons with some disabilities on Brazil, which represents 23.9% of its population. Major part of these persons has one or more types of incapacities: visual, hearing, physical, cognitive and communicative[11].

Disabilities can be originated congenitally or acquired throughout life. Some conditions may cause impairment of physical function, compromising the capability of performing communication. One example is Amyotrophic Lateral Sclerosis (ALS). It is a neurodegenerative disease, progressive and disabling, characterized by a muscular palsy which reflects the destruction of neurons in the primary motor cortex, of the cortical-spinal tracts, brainstem and spinal cord, leading to denervation of nerve bundles and hence the corresponding atrophy of muscle fibers[2; 3].

With advancing disease, there is a progressive increase in the involvement of the muscles of the upper and lower limbs, changes in proximal musculature and finally, affecting the muscles of the respiratory system, culminating in death. However, patients with ALS usually retain their intellectual capacity and level of consciousness preserved[4].

Every year about 1-3 new cases of ALS are diagnosed each 100,000 inhabitants. Yet for unknown reasons, males have higher prevalence compared to females, with ratio of 1.5 : 1, and the average age of disease onset is between 55 to 65 years old[5]. Considering the cognitive ability of the patient, the technological resources serve to assist in its functionality, and the Assistive Technologies (AT) according to the Brazilian Government decree 5.296[6], has the primary objective of enhancing the residual capacities of persons with disabilities, reducing the effects of their disabilities and creating conditions for maximum functional performance of each user[7]. The set of technological and methodological procedures used by individuals suffering from any illness, disability or temporary situation that affects their communication with others for resources commonly used, more specifically speaking, defines a model of Augmentative and Alternative Communication (AAC)[8].

Alternative communication is a process that aims the replacement of speech, while the Augmentative communications aims to magnify and/or complement the existing abilities of speech. Composed of strategies that complement or replace the spoken language, AAC systems are based on pictographic, ideographic symbols. They range from gestures, vocalizations, facial expressions, gaze direction, boards with alphabet symbols or graphics. There is also some high technologic AAC systems like sophisticated computerized systems that synthesize and digitize speech[8].

For building systems appropriate to the needs of each individual, it is important ensure compatibility of hardware and software, enabling the integration of different AAC solutions. Hardware is fundamental to establish a connection between the user and the AAC system, allowing the construction of a Human Computer Interface, capable of processing the user's input for driving different gadgets, such as electronic equipment controllers or graphical interfaces. However, considering that each individual is unique on its limitations, the choice of a sensor to apply on a HCI will always deal with the challenge of searching for signals of advanced control, suitable for each user and for each application[9]. Sensors can be divided into different categories, varying between parameters of different nature, such as chemical, physiological, mechanical, and others. Physiological parameters commonly user are electromyography, electrooculography and electroencephalography. Mechanical sensors involve buttons, pneumatic switch, accelerometers and others[10].

In this work, we have proposed the use a mechanical sensor to control an AAC software. The sensor should be capable of capturing smooth movements performed by different parts of the body (shoulders, hips, neck) of patients with severe motor dysfunction. For this purpose, we have chosen an accelerometer, which consists on a transducer that converts the acceleration applied to the device into an electrical voltage. In other words, the device measures the acceleration according to gravity, responding both frequency and intensity of the movement[11]. This paper presents the analysis of feasibility of a customized hardware in order to control EDiTH a software developed for alternative and augmentative communication[12].

II. METHODS

EDITH

This version of EDITH - Digital Teleaction Environment for People with Disabilities - was developed at the University of Lorraine (France) in the LCOMS Laboratory for an user with ALS. The system was developed for PC, and for reason of convenience and practicality, it has two main components: a functional interface and other for settings[10]. The functional interface (Fig. 1) is the area of interaction for the user, where he can execute tasks such as trigger an alarm, call the medical staff, choose pre-defined sentences, write on a virtual keyboard and access media files (videos, music, pictures, text, pdf). The settings interface allows the configuration of some parameters regarding to the application: scanning time, keyboard's layout, add new sentences, activate/deactivate auto-complete feature and adaptive scanning time.

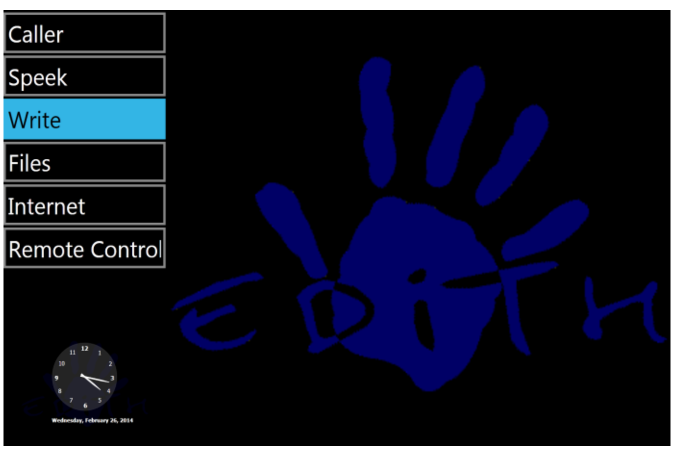


Fig. 1. Edith menu module.

Fig. 2 shows EDiTH's virtual keyboard, which belongs to the Writing Module of the application. It offers an alternative to type keys, simulating the operation of a physical keyboard. The virtual keyboard has a mechanism of automatic scanning, where the screen highlights a column at each time. When the desired column is on focus, the user must select it. Then, scanning shall occur between the items in each row of the column. When the desired character is on evidence the user makes its selection. Thus, a text can be written in the dialog box on the screen.

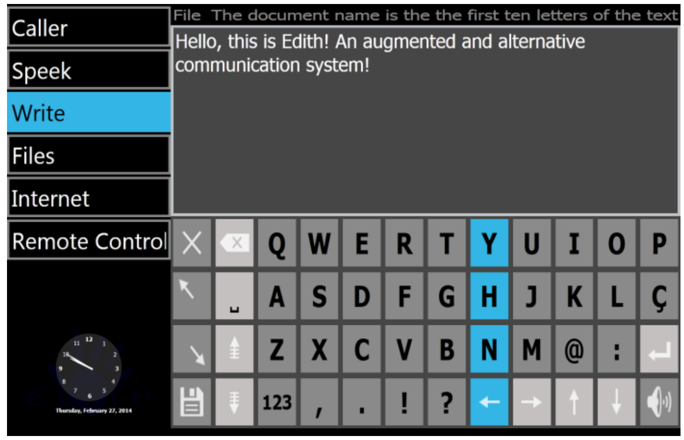


Fig. 2. Virtual keyboard interface.

Each action is performed in the system from the user's sensor. The device sends an electrical signal from the acceleration, resulting from its own displacement. The signal is captured by a port of a microcontroller (MCU), performing the analog to digital conversion. The firmware of the MCU processes the digitized accelerometer's signal, in order to detect a spontaneous movement of the device attached to the user's body. Such event is classified as a command ordered, sending a message to the PC through the serial communication established with the microcontroller. A background application that communicates with the microcontroller calls the event of mouse click allowing in this way the control of the AAC system. The input provided by the user is comprehended as an on/off input. This methodology is compatible to EDiTH's requirements, since the only control action required is the selection of an option among those provided. Every action performed by the subject on the software is registered on a record file, allowing subsequent data analysis. In the current study, the event log will be used to analyze the performance of an accelerometer placed in different parts of the user body for driving EDiTH software.

ACCELEROMETER

In the health field, among a number of possible applications, accelerometry is a method used to analyze movement kinematics in biomechanical analysis. The accelerometer is an instrument used to measure acceleration, which converts acceleration's magnitude into electrical signal. The signal represents the instantaneous value of acceleration versus time, responding to both frequency and intensity of the movement[13]. The accelerometers used for kinematic studies include piezoelectric, piezoresistive, capacitive technologies and all who apply the same basic principle of the mass-spring system[11].

In this study, among a number of available sensors, we have chosen one that could match the following requirements: (1) to capture a spontaneous body movement of small amplitude such those from an user with motor disabilities; (2) to allow adjustment of sensitivity and time response for each user; (3) versatility with respect to its positioning in order to allowing the placing in different parts of the human body; (4) low cost and (5) easy implantation. In this way, the MMA7361 accelerometer was chosen, jointly with a filter for noise attenuation and a proper circuit for temperature compensation.

Among various accelerometers available in the market, it was chosen the MMA7361 accelerometer, a filter for noise attenuation and a proper circuit for temperature compensation. The MMA7361 is a triaxial accelerometer to detect any coordination and voluntary movement in space, according to X, Y and Z coordinates. The module has small size (27.9 mm x 16.8 mm), low power supply (3.3V to 5V, 23mA) and adjustable sensitivity (1.5g and 6g).

The analog outputs (X, Y, Z) were captured, digitized and processed for interacting with the software EDiTH. To achieve this, a microcontroller was used, that consists of an integrated circuit containing a processor core, memory, and programmable input/output peripherals. The accelerometer's signals were recorded from the internal analog-to-digital converter module. The microcontroller (MCU) used was the Arduino UNO, which is called physical or embedded computing platform, i.e., a system that can interact with its environment by means of hardware and software[14]. A parallel application was developed to receive data from the microcontroller, allowing to the user controlling the main application as shown in Fig. 3.

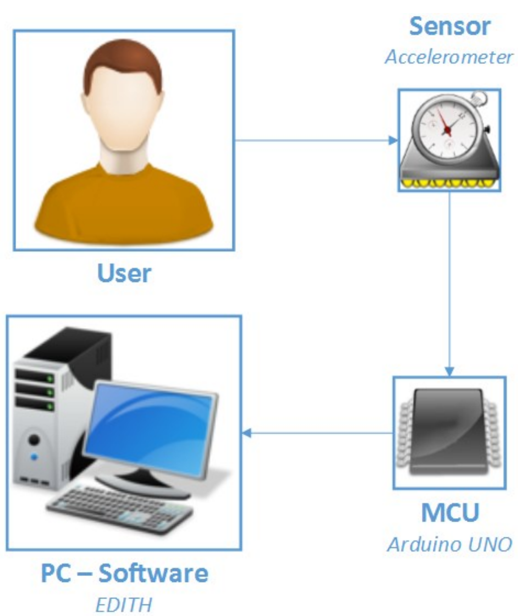


Fig. 3. Block diagram of the system.

EXPERIMENT

The proposed task was using the EDiTH`s virtual keyboard for writing the sentence "GAZETA PUBLICA HOJE BREVE NOTA DE FAXINA NA QUERMESSE". This sentence is a Portuguese-language pangram, that is, one which contains all characters of the Portuguese alphabet. Each volunteer would accomplish the task in three ways: 1 - using the accelerometer positioned over the dominant hand (Fig. 4 - left); 2 - using a mouse; 3 - using the accelerometer positioned on the shoulder of the dominant hand (Fig. 4 - right). For each configuration the user carried out the task for three different scanning times of the virtual keyboard (1000ms, 700ms and 400ms).

The mouse setting represents a sensor of on/off category, enabling the comparison with the accelerometer that is classified as another sensor category. The positioning of the accelerometer would be defined according to the progression of the ALS, because the superior distal muscles (hand) and the proximal (shoulder) deteriorate in different moments.

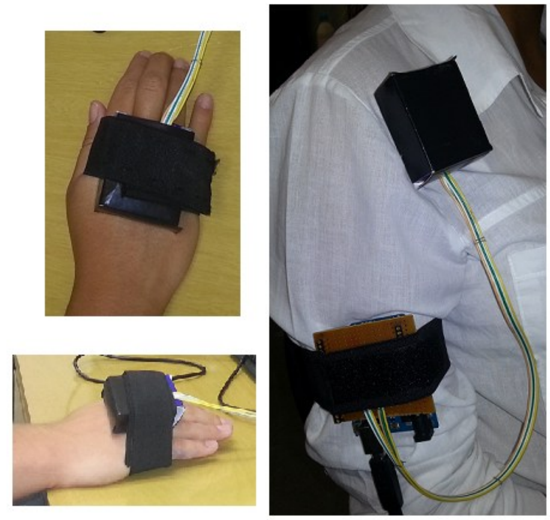


Fig 4. Positions of the accelerometer.

To standardize the learning curve of all participants and not to include biases to the study, the sequence of the devices was set randomly to the first participant and the same order was standardized for the other volunteers. The configuration adopted during the experiment of writing the pangram was the following:

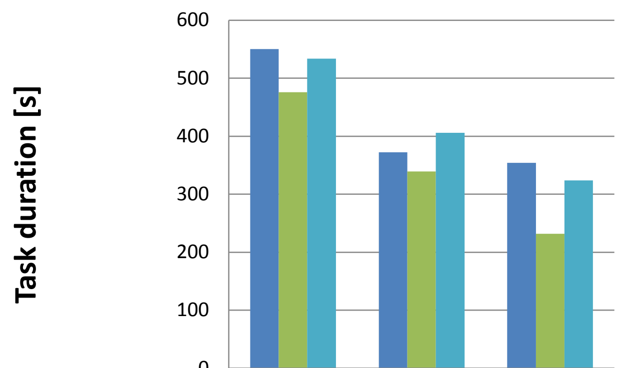
TABLE I. Experiment settings.

Trial	Settings	t_{scan} (ms)
1st	S1: Accelerometer positioned over the dominant hand	1000
2nd		700
3rd		400
4th	S2: Mouse clicking (button device)	1000
5th		700
6th		400
7th	S3: Accelerometer positioned at the shoulder of the dominant hand	1000
8th		700
9th		400

The experiment included 8 healthy volunteers, 5 men and 3 women, 5 with dominance of the right side and 3 on the left. Each command action performed was recorded in a document (log file) provided by the software. For each test, the following parameters were analyzed: duration time to perform the task; number of command signals sent along the task; accuracy rate to click the correct character; reaction time spent by the user to trigger the sensor and select the desired character of the virtual keyboard. From this data was extracted the average of each parameter between all participants of the experiment.

III. Results

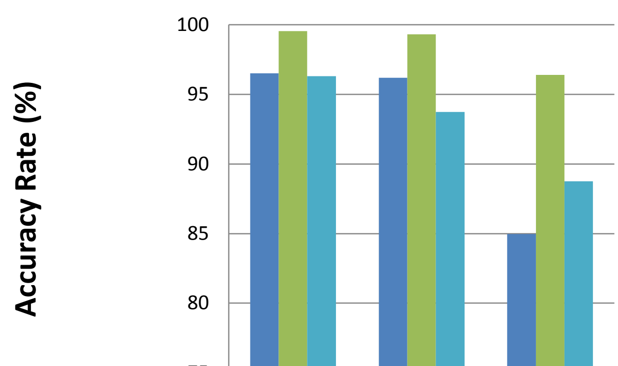
The time average values for selecting a key at each setting is shown in Figure 5 for the three operation modes. Considering S2 as reference, S1 setting increased the task duration by 15.7%, 9.7% and 52.8%, while S3 by 12.1%, 19.6% and 39.7% for t_{scan} of 1000, 700 and 400 milliseconds respectively.



	1000 ms	700 ms	400 ms
S1: Accl. on hand	550,30	372,38	354,16
S2: Mouse	475,79	339,40	231,72
S3: Accl. on shoulder	533,49	405,94	323,78

Fig. 5. Average task time (ms).

Fig. 6 shows the mean values of accuracy rate. For scanning of 700ms, the S1 configuration showed a hit rate of 3.13% less than the performance shown by S2, while the S3 configuration showed a value of 5.62% less than S2. For scan time of 400ms, S1 showed an accuracy rate of 11.87% lower as compared to S2 whereas S3 had a value of 7.95% lower in comparison with S2.

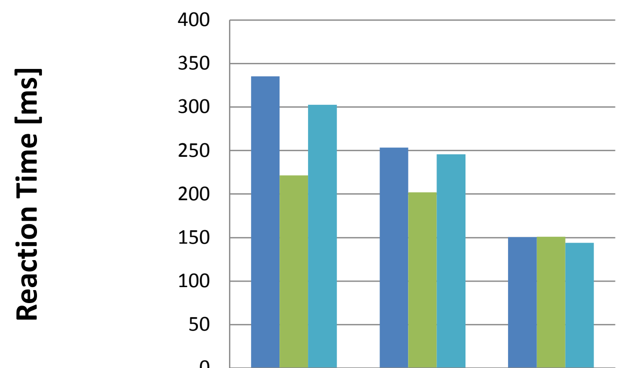


	1000 ms	700 ms	400 ms
S1: Accl. on hand	96,53	96,20	84,97
S2: Mouse	99,55	99,31	96,41
S3: Accl. on shoulder	96,30	93,73	88,75

Fig. 6. Average percent accuracy rate.

The average reaction time, i.e. the time required for the operator perform the click in response to visual stimulus of the highlighted option is shown in Fig. 7.

The user's reaction time allows to evaluate the response time that he takes to perform a task, described as follows: (1) visual perception of the desired highlighted key in the virtual keyboard; (2) cognitive processes that connects inputs from the perceptual system to the right outputs of the motor system; (3) motor action in response to the stimulus; (4) action recorded by the sensor; (5) processing performed by firmware and software; (6) sending the command to the main application to finally selecting the desired key. Thus, it is possible to analyze the performance of a device used as a sensor to capture the action command from the user. According to Fig. 7, for t_{scan} = 1000ms, the reaction time increased 51.6% from S2 to S1, and 36.8% from S2 to S3, while at t_{scan} = 700ms, the same comparisons showed respective increase of 25.3% and 21.6%. At t_{scan} = 400ms, occurred a decreasing of 0.3% from S2 to S1 and at 4.5% from S2 to S3.



	1000 ms	700 ms	400 ms
S1: Accl. on hand	335,49	253,27	150,62
S2: Mouse	221,30	202,06	151,00
S3: Accl. on shoulder	302,73	245,71	144,15

Fig 7. Average reaction time.

The study of this parameter was based on the Model Human Processor (MHP), that is a method of cognitive modeling used to calculate the time required to perform a given task, composed of three interdependent subsystems: the sensory, cognitive and motor, each with their time characteristic: $T_{cognition}$ = [25-170ms], $T_{perception}$ = [50-200ms] and T_{motor} = [30-100ms], resulting in a total time of activity between [105-470ms]. Values of reaction times belonging to the range [0-100ms], [100-400ms] and [400ms-T_{scan}] are classified, respectively, as error/anticipation zone, active zone and delay zone[15]. Based on the reaction times recorded from a volunteer for t_{scan} of 700 milliseconds, figures 8, 9 and 10 were obtained.

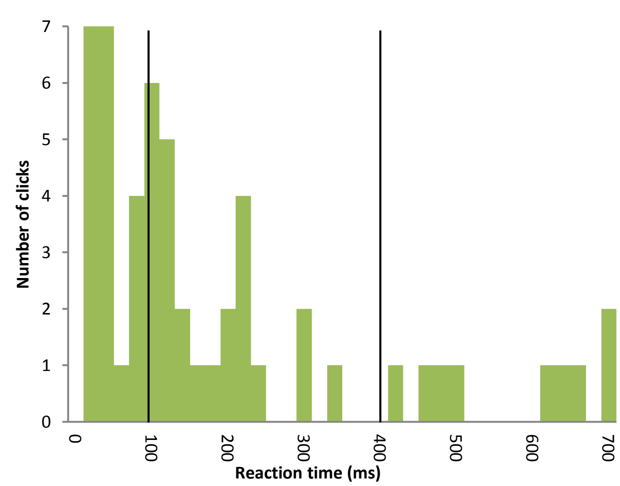


Fig. 8. Reaction time of one individual on S2 setting at tscan = 700ms.

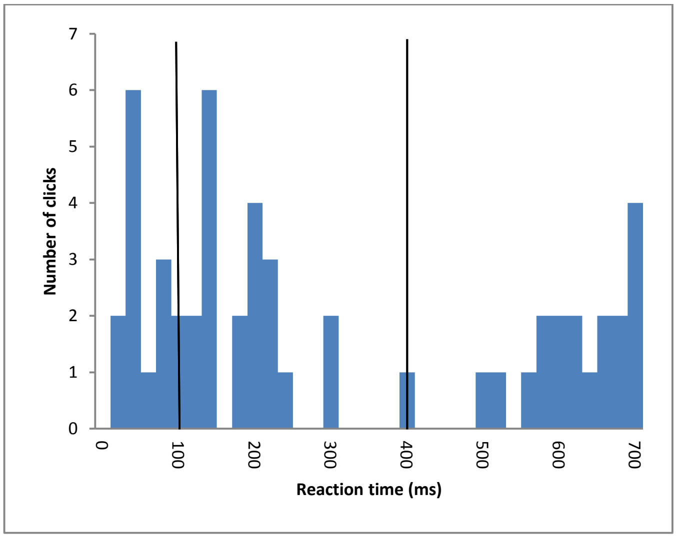


Fig. 9. Reaction time of one individual on S1 setting at tscan = 700ms.

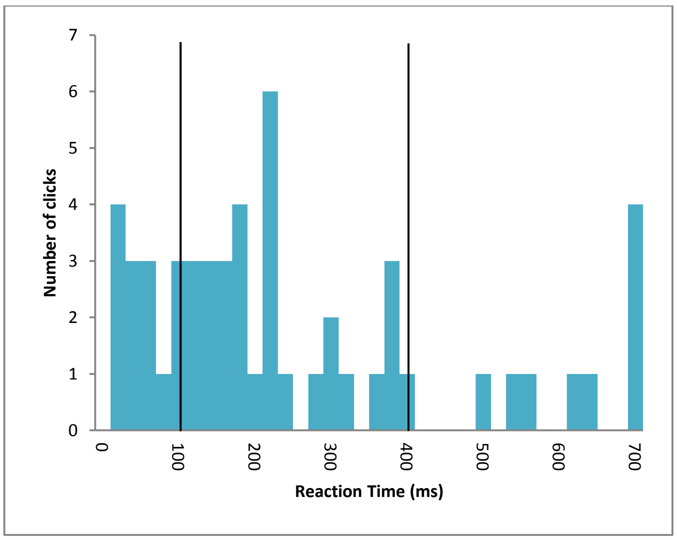


Fig. 10. Reaction time of one individual on S3 setting at tscan = 700ms.

According to Fig. 8, 9 and 10, it is possible to see that for the setting S2, 47.2% of its actions belongs to the active zone, while for settings S1 and S3, 41.5% and 60.4% of their respective actions were in the same zone.

IV. Conclusion

The developed system based on accelerometry enabled the user to complete the proposed tasks in the experiment. The control of the software at this configuration showed values of reaction time and accuracy rate next to a device on / off type (mouse). The accelerometer was tested successfully in different configurations suggesting that this device could be used by people with different limitations. In this scenario, the setting of the sensitivity of the accelerometer would allow patients with various degrees of motor disabilities to control the AAC system.

V. References

[1] IBGE, "*Características gerais da população, religião e pessoas com deficiência*", ISSN 0104-3145, Censo demogr., Rio de Janeiro, p.1-215, 2010

[2] V. Godinho, "*Esclerose lateral amiotrófica: Revisão bibliográfica da patofisiologia*", M.S. thesis, FCS, UBI, Covilhã, DCB, 2013.

[3] C. Madureira, "*Diagnóstico Diferencial de Esclerose Lateral Amiotrófica: A propósito de um caso clínico*", M.S. thesis, FCS, UBI, Covilhã, DCB, 2012.

[4] C. Cassemiro, C. Arce, "*Computerized visual communication in amyotrophic lateral sclerosis*", Arq. Bras. Oftalmol. [online]. 2004, vol.67, n.2, pp. 295-300. ISSN 0004-2749.

[5] M. R. Turner et al, "*Controversies and priorities in amyotrophic lateral sclerosis*", J. , Vol.12, n3, p.310-322, 2013. ISSN 1474-442

[6] Brazilian Government decree n. 3.298, 2004.

[7] R. J. Lederman, "*Bradley's Neurology in Clinical Practice"* JAMA, v. 308, n. 16, p. 1694-1694, 2012. ISSN 0098-7484.

[8] M. Danelon, "*As Interações Sociais de Alunos com Dificuldade de Comunicação Oral a Partir da Inserção de Recursos da Comunicação Alternativa e Ampliada Associada aos Procedimentos do Ensino Naturalístico"*, Ph.D. thesis, EDU, UERJ, Rio de Janeiro, RJ, 2009.

[9] C. Pinheiro Jr et al., "*Alternative communication systems for people with severe motor disabilities: a survey*". Biomedical Engineering Online 2011 10:31.

[10] L. Rocha, "*Interface Multimodal Aplicada à Comunicação Alternativa para Pessoas com Deficiências Motoras Graves*", M.S. thesis, FEELT, UFU, Uberlândia, MG, 2013.

[11] C. Cescon et al, "*Effect of accelerometer location on mechanomyogram variables during voluntary, constant-force contractions in three human muscles*", Medical and Biological Engineering and Computing, v. 42, n. 1, p. 121-127, 2004. ISSN 0140-0118.

[12] E. Naves, L. Rocha, P. Pino, "*Alternative Communication System for People with severe motor disabilities using myoelectric signal control*", Biosignals and Biorobotics Conference (BRC), 2012. ISSNIP: IEEE, 2012. p. 1-4.

[13] D. Corrêa, "*Desenvolvimento de um sistema para estudo da marcha humana por videogrametria e acelerometria*", Bachelor thesis, DELET, UFRGS, Porto Alegre, RS, 2010.

[14] M. McRoberts, "*Beginning Arduino*", Apress, 2010. ISBN 1430232412.

[15] S. Ghedira, P. Pino, G. Bourhis, "*Conception and Experimentation of a Communication Device with Adaptive Scanning*". ACM Trans Access Comput 2009, 1:1-23.