Abstract—This article proposes the development of a mobile interface for controlling a Neuroprosthesis, designed to restore grasp patterns, aiming tetraplegics users at C5 and C6 levels. Human Computer Interface paradigms and usability concepts guide its planning and development to guarantee the quality of user's interaction with the system and thus, the success and controllability of the neuroprostheses. The number of screens and menus were optimized, thus the user may feel the interface as more intuitive, leading to fast learning and increasing the trust on it.

I. INTRODUCTION

Spinal cord injuries can be caused by a variety of trauma accidents, where the sectioning of the spinal cord occurs, as well as through tumor and bad formation during pregnancy. A lesion comprehended at cervical area characterizes tetraplegia, where the person loses part of his motor function of upper and lower members, and can be more or less severe depending on the level of injury [1].

Subjects with cervical injuries at levels C5 and C6 keep only the motor control of arm, forearm and wrist, the last one in case of C6 injury. At this levels, subjects have no motor control of the hands, not allowing grasp movements. Depending on the injury’s severity, it is possible to occur what is called denervation, that is the loss of some specific nerves function, and since it doesn’t happen, there is the possibility of using Neuromuscular Electrical Stimulation (NMES) systems to restore grasp patterns artificially [1].

Regarding a NMES system, the quality of its control interface has huge importance for one to take the greatest benefit of it. This article presents a proposal of a mobile interface for smartphones, to control a neuroprosthesis, carefully planned and developed based on Human Computer Interface (HCI) paradigms and usability concepts.

II. CONCEPTS

A. Neuromuscular Electrical Stimulation

For the last two decades, many studies and projects of neuroprosthesis aimed to recover grasp patterns were developed, although only a few of them were focused on the final user, limiting considerably the range of options to the tetraplegic get back to have, even in parts, his autonomy recovered. Either for high costs, or not having a good level of miniaturization and mobility, the most of NMES systems still on the market are almost totally focused on physiotherapy, consequently impracticables for daily use as a real neuroprosthesis.

In the 80’s the Freehand System was developed, one of the greatests and more important studies in the area of grasp pattern recover, being a neuroprosthesis of invasive approach, provided with 8 stimulation channels to restore palmar and lateral grasp patterns and controlled by a position sensor on the contralateral shoulder [1]–[4].

The Freehand System was commercialized until around 2001, being replaced by the IST-12 System, provided with 12 stimulation channels and 2 electromyography acquisition channels for its control. The system was able to restore palmar and lateral grasp patterns, and also shoulder extension and forearm pronation, making possible the reach of objects above the head line [1]–[4].

Systems with non-invasive approach were also developed. The Bionic Glove is an example, and it was consisted by a device recovering palmar and lateral grasp patterns, which selection mode was performed through a button at the main module, as well as its stimulation intensity through a wrist extension sensor. The Bionic Glove was focused on persons with injury levels at C6 and C7, as well as the ones affected by stroke [5].

In the year of 2012, motivated by the lack of options to the Freehand System, researchers decided to create a non-invasive system with the same functionality, recovering palmar and lateral grasp patterns, also controlled by contralateral shoulder position sensor. This system was created based on a general use stimulator, commonly used on physiotherapy, the Motionstim 8, manufactured by the Dutch company Medel. This stimulator provides 8 stimulation channels and wide range of parameter adjustment, such as frequency, period, type of waveform, among others [6], [7].

Currently in production, the Bioness H200 system, manufactured by the company Bioness Inc., resembles the previously mentioned Bionic Glove system, being a futuristic looking neuroprosthesys, containing electrodes and stimulator module together, mainly focused on people who suffered from stroke. This system receives commands from a radiofrequency control mode or also by wrist extension, through which hand opening or closing commands can be requested, for instance at holding or releasing a door handle [8].

Regarding specifically the control approach, it is quite common for neuroprosthesis for grasp pattern restoration, the usage of position sensor at the contralateral shoulder, together with some buttons to select operating mode. There are some exceptions, like the IST-12 system, which uses the electromyography acquired at the musculature between shoulder and neck, as well as Bioness H200, which can receive commands from an external remote control.

About the position sensor for using on the contralateral...
shoulder, commonly used on this kind of neuroprosthesis, some favorable and unfavorable points can be listed:

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Relatively low cost</td>
<td>Need of wearing the sensor correctly</td>
</tr>
<tr>
<td>The usage under the clothes</td>
<td>Non-intentional movements are reflected on the stimulation</td>
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<tr>
<td>make it discreet</td>
<td>Keeping a fixed shoulder position can become uncomfortable</td>
</tr>
<tr>
<td>Proportional control of stimulation</td>
<td></td>
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<tr>
<td>intensity</td>
<td></td>
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</table>

This article makes reference to a neuroprosthesis being developed for daily use, utilizing current technologies at hardware and software. The proposed hardware for this use uses non-invasive approach, providing 6 constant current-controlled stimulation channels, with palmar and lateral grasp patterns, and in addition to it, index extension for typing.

Due to the intelligent mobile phones dissemination, called smartphones, the control interface proposed to work with the neuroprosthesis is an app for them, communicating with the neuroprosthesis through bluetooth. The interface was developed based on HCI theory, allowing its use with minimum effort, as well as making possible the user’s self learning without difficulty. Well planned interfaces don’t leave doubts to the user, since having at least a few experience with computational applications, and for the ones who doesn’t, the objective and clean organization of menus, invite them to give it a try.

B. User modeling

User modeling can be described as a tool by which an application can be more useful, flexible, filling the gaps in the user’s previous experience [9]. Analogously, an Adaptive User Interface can be understood as an interface that can improve its own capacity of dealing with the user, based on the previous experience with that same user [10].

At HCI, user modeling is important due to the fact that it carries an improvement potential of collaborative systems of human machine, in other words, the developers write their applications for thousand of users, and from the user’s point of view, it seems that the applications were uniquely developed for them.

In order that an adaptive system is not able to change its status at real time, immediately, as long as an user interact with it, the usage of some sort of previous information is necessary, in order to get knowledge about his behavior. This way, based on a previous data collected from the user, or from a group of users, the interface can get to be more or less customized, and/or individualized.

Initially, it must be clear that every single application, adaptive or not, brings an implicit user profile, defined during the planning phase. Ideally, this profile should be based on a careful previous study with the target population. The terms and visual resources must be adapted to that specific population of interest, in order to optimize the user interaction to the application.

C. Adaptive user interface

As mentioned previously, and adaptive interface can be described in a few words as an interface which adapts itself to the user, instead of the user to adapt the interface [11], although others similar definitions could be given. It could be said that an adaptive interface has the capacity of changing its content and available tools to meet the user’s objectives in that given situation [12].

An adaptive system makes use of many knowledge areas, such as artificial intelligence, user modeling, psychology, planning, among others. Smart user interfaces can receive some classifications. An important differentiation of therms must be done between adaptive, adaptable, and adapted systems [13]:

1) Adaptive systems basically monitor the user’s behavior and records some aspects of it, offering later customizations to him, according to his experience;
2) Adaptable systems are the ones that allow its manual customization, according to the user’s preferences, commonly offering help resources or ‘wizards’;
3) Adapted systems are the adaptable ones, after a customization done by the user;

Beyond the fact of customizing the system’s presentation, actions such as reduce the excess of duties for the user, reduce excessive information or filtering problems, as well as provide help and tutorials are challenges to be overcome for an intelligent user interface [13]:

1) Reduce the excess of duties for the user: The system must be skilled enough to the point of noticing the user’s intention and offer more direct ways to reach it;
2) Reduce excessive information or filtering problems: Knowing the user, potentially not-relevant information can be suppressed of lists when showing data;
3) Provide help and tutorials: Due to possible updates providing new resources, less skilled users cannot notice or don’t understand how to use them;

III. Development

The proposed mobile interface for the neuroprosthesis, was developed using usability methods and project modeling techniques. In this section, the problem scenario, the user profile and modeling technique will be detailed. The initial version of the interface, running on Android devices with 5” screens, is detailed on section IV.

The evaluation, as well as the good practices for the application development, were based on Nielsen’s heuristics [14], largely known and applied at HCI area. Next are some contributions to the application extracted from it:

- System state visibility, where the user has awareness of the processes in progress;
- Correspondence between system and real world, avoiding utilizing technical terms;
• Control and liberty to the user, keeping in all screen ways to interrupt the neuroprosthesis operation instantly;
• Aesthetic and minimalist project, not polluting the interface with redundant information;

A. Problem scenario

The problem scenario referring to the use of a common neuroprosthesis, that is, without the mobile interface proposed here, can be defined as:

1) The user asks for help to wear the neuroprosthesis on his forearm, positioning correctly the electrodes, as well as the position sensor on his contralateral shoulder, and the switch on the chest (when available);
2) The user, if possible, connects the cables of the position sensor and chest switch on the main module of the neuroprosthesis. If he can’t, help from another person will be necessary;
3) The user turns on the neuroprosthesis and perform some tests to verify the correct positioning of the position sensor and electrodes, reallocating them if necessary;
4) The user configures through switches or rotative controls the intensity and frequency of pulses, if available and necessary;
5) For each type of grasp desired, the user presses the chest switch to select and performs movements of the shoulder to gradually control the intensity;
6) To stop the stimulation, the user keeps the chest key pressed for a couple of seconds;

B. User profile

To the system’s viability study, the defined user profile is described next. Based on the main characteristics of the target public, the application modeling has greater chances of corresponding to the user’s expectations.

• Gender: Indifferent;
• Age: Teenagers and adults, aged between 15 and 50 years old;
• Injury age: 3 years at most;
• Experience: Basic on technological equipments, just like computers and smartphones;
• Interests: Interest on testing non-invasive neuroprosthesis to recover grasp patterns;

C. Task modelling technique: Adapted Hierarchical Task Analysis

To the task modeling of the whole system, the Hierarchical Task Analysis (HTA) was utilized. On the first version, buttons to pair with the neuroprosthesis, adjusts, test the electrodes, as well as 3 functions with intensity adjustments were utilized. Figure 1 shows the correspondent diagram.

The symbols at HTA diagram are described below:
• Underscore: Operation, and no underscore, objective;
• Dashed edges: Optional task;
• Numbers: Sequential tasks, and with question marks, independence;
• Dot: Ubiquitous (accessible tasks at any time);

D. Prototyping of the mobile application

For the initial prototyping of the application screens, the web tool Lucidchart (www.lucidchart.com) was used, where minimal functioning screen for Android devices could be drawn.

The fact that the interface is focused on tetraplegics users, implies on special characteristics in comparison to common applications. The interface uses greater and more spaced buttons, due to the lack of dexterity of the users on hand movements or even the impossibility of controlling them.

Another explored resource on the application is the change of screens via lateral swipe, once a great number of buttons or scrolling bars could mean extra obstacles for the user.

On the top of the interface, a kind of ‘address bar’ is exhibited, which focus is changed at every screen change, turning it easier for the user locating the current screen at the software as a whole, as well as knowing where to swipe to go to the option he wants.

As previously mentioned in section II-B, technical terms related to the neuroprosthesis as Hertz (Hz), milliampere (mA), microseconds (µs), were substituted by simpler ones, easier of being interpreted, as percentage for instance. Beyond simpler terms, small and objective text boxes are exhibited on some screens, minimizing the possibility of doubts by the user.

IV. Results

Figure 2 shows an example of screen of adjustments, where it is possible to visualize items related to HCI theory, detailed in section II and subsection III-D, always focusing on usability.
The practical development after determination of screens structure, is being performed with the web tool 'MIT App Inventor‘ (appinventor.mit.edu), where it is possible to create an Android application in a simple and intuitive way.

As the number of screens and menus become optimized, the user can feel the interface as more intuitive, leading to fast learning and increasing the trust on it.

The adaptability has potential to provide better experience to the user, whereas with its use, the application changes some of its characteristics, easing and optimizing itself.

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Fig. 2. Application interface example. Source: Author

The initial version of the application is exclusive to smartphones with screens of 5 inches. The multiscreen feature can also be provided in the subsequent versions.

It is not necessary complex algorithms to have an adaptive application. Simple steps as listed below, could bring to it phones with screens of 5 inches. The multiscreen feature can accommodate the available functionalities at the interface.

- Resizing of graphical area according to the device where the application be installed;
- Storage of configurations in disk, so that the application doesn’t need to be configured every time;
- Provide shortcuts to the more commonly used functions, arranged by frequency of use;

V. CONCLUSIONS

With this interface, the tetraplegic user finds a practical and intuitive way to control his neuroprosthesis, associating the simple control with the functionality of the modern smartphones of nowadays.

The methodical evaluation, realized by interface testers following Nielsen’s heuristics, as well as the practical evaluation of the target population, contributed to the maturation of the application, making it more intuitive and error-proof.

The conceptual model built, presents the screen structure to accommodate the available functionalities at the interface. This model brings a set of screens that are defined as ‘paper prototype’. The prototype is used to validate the functionalities, its descriptions, as well as the element distribution at the screen. As the integration with the hardware wasn’t done yet, the interface was evaluated only under conceptual aspects, following the heuristic inspection. The interface will only be tested by the target population, after the future integration with the hardware.