A User Centred Approach for Developing Brain-Computer Interfaces

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***Abstract*—Brain-Computer Interface (BCI) research requires a multi-disciplinary approach. The core concept harnesses brain wave activity to enable a user to interact with devices without the need for physical activity. There are many possible benefactors of such technology, including rehabilitation, supporting disabled people in everyday activities and the gaming industry. This is a science that has been in the embryonic stage for some years and there has been a recent push to develop the technology for application outside of the laboratory environment. This paper gives details of developments within the European Union (EU) funded BRAIN project whereby the goal is to achieve an easily used BCI system for operation in a domestic environment. More importantly, as much of the BCI community's research to date has been in the advancement of the scientific signal processing and paradigm development there has been less attention to the user aspects of the BCI system. In contrary a user-centred model of development is employed in this project.**

Keywords- Brain Computer Interface; BCI; user centred design; user engagement; participatory design; user interface; lead user; Steady State Evoked Potential; SSVEP; high frequency SSVEP

I. Introduction

The area of Brain-Computer Interface (BCI) technology promises to be an enabling and inclusive technology for people with severe physical disabilities. Disease and traumatic injury can lead to range of degenerative pathologies, for example amyotrophic lateral sclerosis (ALS) with the subsequent development of 'locked-in syndrome' in severe cases, where a person cannot move or communicate in any voluntary way but they are both aware and awake [1]. The ability to interact with people and devices could have a huge impact on the inclusion of such people and help users reclaim some control of their daily lives and perhaps help them to manage aspects of their own care [2][3]. To date, a number of applications have been controlled through BCI [4][5][6]. Yet the technology has not reached the maturity to escape the laboratory setting. Moreover, a range of applications may exist but they are typically developed in isolation by different research groups each favouring a particular BCI paradigm, resulting in applications that are incompatible between systems. This limits the potential user benefit. Furthermore, expert technical help is needed at various stages of the BCI use. Again, this does not provide for a usable system. In addition, equipment comprising electrode, cap, amplifier, computer and stimulus device is prohibitively expensive (usually greater than €10,000) and is not aesthetically appealing.

This paper presents user interface work undertaken as part of the BRAIN project [7]. This European consortium is funded within the 7th Framework Programme of research bringing together experts from academia and industry with service users to develop a BCI system linked directly to assistive technology and services within the home environment. The project goal is to simplify, unify and expand the BCI system making it a practical and affordable enabling technology supporting inclusion for a range of disabled users.

A user-centric design approach was adopted (Figure 1). Much of contemporary BCI research focuses on the technology development without a direct involvement and engagement of the user from the earliest stages of the development of the concept. The research methods used by BRAIN are designed to support a strong user-orientated focus within both design and evaluation of the prototype system. The involvement of a lead user has been a critical innovation within the consortium influencing design of methods and prototype.

This lead user concept has evolved in the literature in management science where it has been shown that an accurate understanding of the needs of users is critically important for the successful development of commercial products [8]. A lead user is a user whose needs match closely to the expected market needs that will arise in the future, and who will add new and perhaps unexpected insight into the design process [9].

Furthermore, the project is also user focused in that the goal is to develop a BCI system that can be tailored specifically to the user in terms of the technology and the applications. This in itself is novel as previous designs have acted more as a proof of concept rather than providing a usable and varied system [10].

Section II will give an outline of the research methods employed in BRAIN. A technical outline of the key areas for development is summarised in Section III. Details of the paradigm for evaluation will then be detailed in Section IV, reporting initial advances in the high frequency Steady State Visual Evoked Potential (HF-SSVEP) BCI developed within

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the consortium [11][12]. This is driven by our developed user interface. Details will be provided on the user involvement in each of the design and evaluation stages in Sections V to VIII. Results are discussed in Section IX and the paper will conclude with an overview of current and future developments and goals.

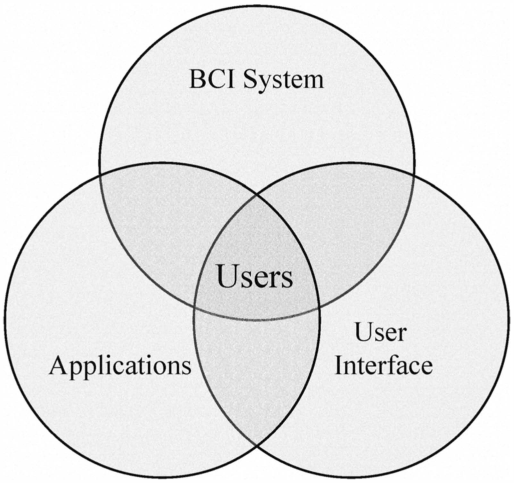

Figure 1. User centred design

II. RESEARCH METHODS

The project consortium developed a methodological framework. This was useful in guiding the ethical review and technical review required in advance of engaging with users. BRAIN has adopted a user-centred design approach, involving two separate groups of participants, one with disabled users and one with healthy non-disabled users, in association with two institutions:

- The Cedar Foundation, Northern Ireland: Disabled users
- Telefonica, Spain: Able-bodied users

The University of Ulster (UU) also engage in iterative user evaluations as a preliminary investigation before trials are rolled out to the Cedar tenants. For their investigations they engage with the Lead user and a number of healthy non-disabled subjects.

The Cedar Foundation [13] provides technology-enriched supported housing options for people with physical disability and acquired brain injury. They are the workpackage leaders for co-ordinating user engagement, requirements gathering, user evaluation and project development feedback. Within Cedar they are focussed on the project involvement of disabled users.

In Spain, Telefonica, co-ordinate with a group of able-bodied users. The objective of the participation of a number of healthy non-disabled users is twofold:

1. To act as control subjects in relation to the disabled users. The results from healthy users make it possible to evaluate the impact of different disabilities on the BCI response to high frequency visual stimulation.
2. To evaluate the degree of acceptance of the BCI paradigm (in this example it is HF-SSVEP BCI) among healthy users. This is a crucial aspect for the possible commercialisation of this technology at a large scale

In the early stages of design, quantitative and qualitative techniques were used to gather user requirements. Once gathered this information was used to develop the technical specification for the user interface and the applications that it would be targeted to support. The development is an iterative process. The BRAIN project spans three years. At various stages in technical development there will be a prototype evolution each targeting a new element or furthering an existing one. Our approach is such that at defined periods, evaluations will be carried out within the UU, Cedar and Telefonica sites. This feedback will be used to improve the development, and so users are involved in an iterative design cycle (as depicted in Figure 2).

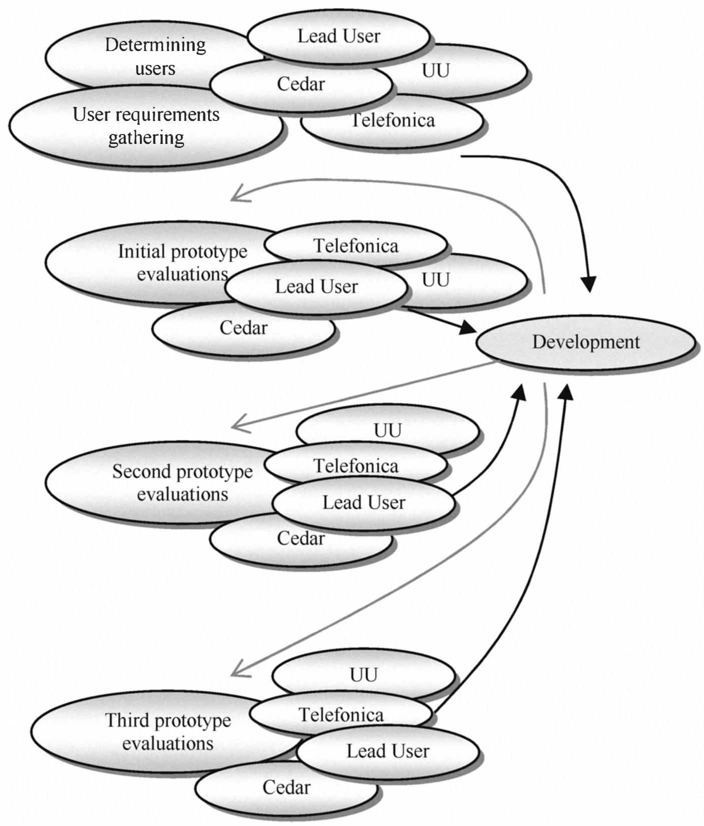

Figure 2. Iterative stages of user involvement

At the outset of the project it was necessary to determine suitable users. For Telefonica's involvement with healthy users there were a number of selection criteria. The user:

- Should not suffer any significant disability
- Be aged (20-60 years)
- Have a good disposition to try new experiences

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- Should be proficient in the use of the typical home electronic devices: TVs, DVDs, mobile phones, computers, etc

There should also be appropriate gender representation.

The involvement of disabled users was more targeted to suitability in terms of user disability, user interest and ethical process. In Northern Ireland (United Kingdom), the Cedar Foundation convened workshops and individual interviews. A purposive sample of tenants, living independently within a Cedar Foundation's supported housing, option were invited to join the project. An initial meeting was set up to determine interests and suitability of tenants in the participation of the project. Out of this investigation one user emerged from the group as the lead user and four others showed an interest in being involved with the project. The participants included one male and four females. The lead user is a male who is a graduate, BSc in Computing. One of the participants has no verbal communication skills. Three participants have congenital disabilities and two have acquired neurological conditions.

During the initial meeting each participant tenant was offered a face to face meeting with the researcher and invited to have a formal or informal carer present. During these interviews the researcher assisted the participant to complete a questionnaire and gave some personal perspective on living with a disability. All participants were keen to take part in the project and very interested in the BCI development. Those participants who were interviewed face to face expressed an appreciation of the value of BCI technology and a sense of satisfaction of being involved in the development process. Only one participant was unsure if they would use the technology, all the others were keen to try it. A total of fifteen people participated in the users' sessions at a Telefonica site in Spain. These users did not have any communication impairments and represent the possibility of effecting BCI uptake for gaming and leisure activities. The quantitative research was conducted by focus groups, of eight and seven participants each and the quantitative part was gathered from surveys delivered to users. The results of the user survey influenced the design of the user interface, and the target applications. The user and system requirements were then developed with this input. They have provided key information for our development.

III. Project Overview

There are a number of different areas for system development: signal acquisition, signal processing, user interfaces and applications (Figure 3.). In isolation each of these components provides a substantial contribution to BCI research but would not migrate the technology to the domestic environment. However, collectively, they provide a platform from which to develop a user friendly BCI system suitable for application outside of the laboratory.

The acquisition of data for the BCI requires recording the user's electroencephalogram (EEG) using electrodes making contact to the scalp at particular locations, typically with the help of a cap that can be uncomfortable and visually off-putting. The use of conductive gel to reduce impedance requires the user to wash their hair post recording. This is something than can in itself be an arduous task for the disabled user. Within BRAIN, research is underway on the feasibility of using either 'dry' or 'water-based' wet electrodes, thus eliminating the need for extensive cleanup [14]. At present there is still a need for a trained carer or a specialised technician to apply the electrodes to the correct location and to check for the quality in the EEG signal. The obvious progression would be to develop EEG head gear that is specific to the user, and the applications that they wish to perform, yet requires limited expert intervention.

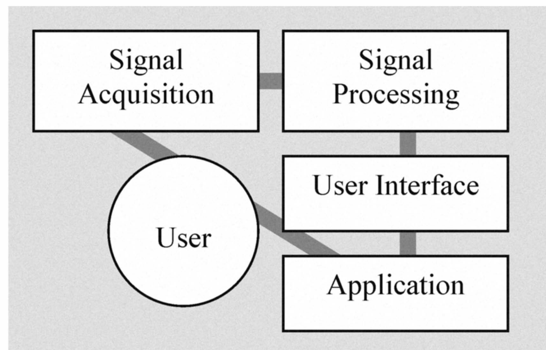

Figure 3. Main components of a BCI system

The next stage of the development is in the signal processing. In setting up a user with a BCI system there are certain customisations that need to be performed to enhance the signal quality and capture the intended information. This needs to be part of a semi-automated system that can be handled by a carer with limited training.

In BRAIN, three BCI paradigms are intended to be supported, namely, SSVEP, the P300 and ERD/ERS. Each will be summarised here. The SSVEP is a visual based paradigm whereby the action of interest flashes at a particular rate (8–50 Hz [11][12]) leading to a response in the viewer's EEG that occurs at the same rate. It has proven successful in a number of example applications. However there are limitations on the number of flashing items that can be used as each must respond to a unique frequency. The number of frequencies supported is user dependent. There is a limited window of frequencies in which a user will respond with a distinguishable response. The more receptive the user is the closer together the stimuli frequencies can be. However, if they are too close then separation of the responses cannot be guaranteed. Moreover, some flashing rates can be an annoyance to the user. If it is too slow then it may become tiresome to the eyes thus limiting the length of use. Other problems can arise with waning user concentration and physiological habituation effects. BRAIN has also been involved in the development of HF-SSVEP [11][12]. At rates above 30 Hz the user will not recognize the flash and will find the rate more easing on the eyes. This enhancement comes at a cost of signal quality, in particular a poorer signal to noise ratio, making it more difficult to differentiate between frequencies. This development and the user trials that were performed using this algorithm were the focus of our first user encounters.

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The P300 paradigm is often referred to as the '*odd ball*' paradigm [15]. Here the elements of interest flash at random intervals. When the user views an unexpected flash of their item of interest then this is represented by an evoked potential in their EEG 300ms after stimulus onset. A number of repeats are needed to ensure decision accuracy. The exact number is user dependent and relies on the susceptibility of the user. User concentration is needed and over familiarisation can lower the P300 response.

The ERD/ERS paradigm does not use a stimulus and is based on imaging movement. For example, while thinking of moving a left limb then activity could be determined on the right hand side of the sensory motor region of the brain, and vice versa. There are other imagined paradigms; such as relaxation, other movement and calculation [16][17]. Typically this paradigm can enable a two way decision. Three and four ways decisions are possible but are less commonly achieved by the user. Imagery requires significant training of the user. It also requires concentration. The user has to relate certain imagined movement to a particular decision. They could easily make a mistake in this process.

The BRAIN goal of incorporating all three paradigms is to allow the BCI to be tailored as much as possible to the user themselves. Not all paradigms will work with all users. BCI illiteracy across the BCI paradigms is recognized and some users will not respond to stimulus while others may have a poor response [18]. Others will have difficulty with the imagined movement. Further issues lie also with disorders that will create artefacts within the EEG due to uncontrolled movement and spasms. Concentration and a level of understanding are also required to engage with these BCI paradigms; which is also a significant design and implementation challenge. Expert system software developed within BRAIN will identify the best BCI parameters for each user and customise the operating protocol accordingly. Issues being addressed include ambient conditions, environment, and the complexity of the user's condition e.g., additional movement artefacts and reduced periods of concentration.

An intuitive universal interface is a key component of the BCI system. The focus here concerns the application architecture and modes of user interaction. It will enable control of a range of existing applications, including home assistive technologies, a BCI training system to enhance performance, and a communications and entertainment package. This has been developed within BRAIN in a generic manner, producing a flexible architecture for both the user and the range of applications it can support. This has occurred through the development of two closely related and interlocking components as depicted in Figure 4.

- Universal Application Interface (UAI) – This component hides the complexity of interacting with different applications and aims to provide a wrapper for unifying and integrating diverse standards and protocols for smart home automation and control into a single flexible application; thereby providing a single point of device command interaction.

- Intuitive Graphical User Interface (IGUI) – This is the visual aspect of the design with which the user interacts. It provides an on-screen menu structure that interacts with the UAI to achieve device control. The IGUI also interacts with BCI components implementing HF- SSVEP.

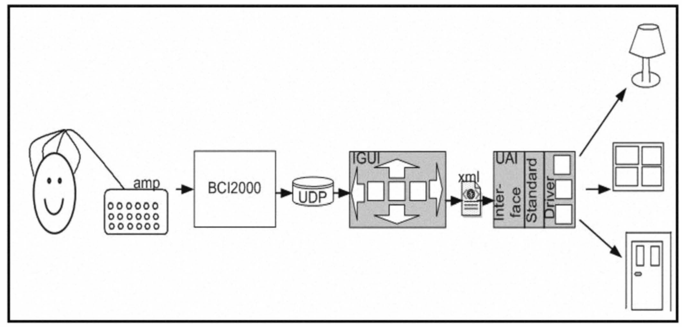

Figure 4. Main components of the BRAIN BCI system

Figure 4 depicts the UAI and IGUI working with the EEG amplifier connected via BCI2000, a paradigm and signal processing package, commonly accepted by the BCI community [19]. The signal processing within the BCI2000 modules produce decision classifications to be employed by the interface. The IGUI and UAI interact through a common eXtensible Markup Language (XML) menu definition file. Some of the complexities are not visible within this figure but it acts to highlight principles within the BRAIN system. Figure 5 depicts the IGUI using a four-way command controlled by SSVEP using light emitting diodes (LEDs), one relating to each arrow and flashing at a unique rate, and corresponding to a unique decision classification. Navigation is feasible through a list of menu items (left or right), selection of a menu item (down) or exit from a menu item (up).

Figure 5. Four-Command Interface showing high level location menu by the IGUI. Four LED's correspond with arrows to provide the command interface

IV. SSVEP PERSONALISATION

The HF-SSVEP paradigm used offers flicker rates between 30-48Hz, in a minimum of 2Hz increments. However users may not be able to avail of this full spectrum, which could

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limit command options and speed of use. The ability to identify rates of flicker and the required size of the increment between flicker rates needs to be established per user. Ideally a four-way decision is desired. Where this is not the case, the strategy of using phases of operation over time must be adopted in such a manner as to allow identification of four possible classifications, as illustrated below:

Example 1: The user has the ability to identify four separate flicker rates at increments of 5Hz (30, 35, 40, 45Hz). As standard operation, the IGUI displays three icons relating to three menu options and the four command arrows referring the user to the appropriate LED's. In a single instance in time each of the LED's flickers at its allocated rate. The user's attention is focused upon the LED, which corresponds to the command of choice. The BCI2000 module detects and classifies a signal sending a User Datagram Protocol (UDP) packet to the IGUI, which then activates the appropriate arrow on screen. If the command was a left arrow then all menu items would be moved over by one step leftwards, making another icon the leftmost menu icon and therefore the highlighted candidate icon for command purposes and displaying a new leftmost menu option.

Example 2: The user is only able to identify a single increment of flicker within a narrow band of HF-SSVEP giving 30 Hz only as the effective operational flicker rate of the four LEDs. In this instance in order to detect each of the required four classifications each LED must flicker at the appropriate rate in turn and the users reaction measured within the appropriate time phase. Once more the three menu icons and four command arrows are displayed by the IGUI. In turn each LED corresponding to a single command arrow flickers at 30 Hz. The user focuses upon the LED of choice. Only when the LED corresponding to the desired arrow is flickering, then the detection and the classification made.

Clearly example 1 offers a faster and therefore more effective interface for the user than example 2. In this manner operation of the IGUI is dependent upon user capability with respect to the available spectrum and increments within the spectrum. Accuracy of operation is dependent upon the possible increments being sufficiently distinctive. It may also be possible to offer a hybrid interface for users who can achieve a detection capability, which lies between examples 1 and 2. In conducting preliminary user tests it is therefore desirable to analyse the potential spectrum of operation and the required increments in flicker rate within the spectrum. Potentially this data can be used as a feedback mechanism in determining strategies for optimising signal processing and IGUI operation. An expert system is under development to facilitate optimisation of parameters for each user.

V. Stages for Evaluation

Figure 2 illustrated that the evaluations within the project are iterative spanning the three years of the project. The first prototype, as discussed, is for HF-SSVEP BCI integrated with the full system and user interface. The section below breaks this process down further providing more detail of the user involvement within the design flow.

Prototype 1: HF-SSVEP BCI fully integrated system with user interface:

- Development of HF-SSVEP BCI
- Development of IGUI and UAI
- Integration of HF-SSVEP BCI and user interface
    - Proof of concept
    - Testing operational and integration issues with Lead user and healthy subjects
- Evaluation of **Prototype 1**
    - Suitability of HF-SSVEP on healthy non-disabled users
        - Feedback and changes made
    - Evaluation of HF-SSVEP with user interface with healthy non-disabled users
        - Feedback and changes made
    - Suitability of HF-SSVEP on disabled users
        - Initially with Lead user
        - Feedback and changes made
    - Evaluation of HF-SSVEP with user interface with disabled user
        - Initially with Lead user
        - Feedback and changes made
    - Full testing on Cedar tenants
        - Suitability of HF-SSVEP
        - Full system testing

This process would be repeated for the next prototypes for the P300 and ERD/ERS paradigms.

VI. Methods for Evaluation

The subjects participated in six thirty-minute long sessions spread over six different days. Four oscillatory visual stimuli at 30, 35, 40, and 45 Hz were simultaneously presented to the subjects. The stimuli were rendered using LEDs positioned next to the outer edges of the screen (Figure 5.). The current on each LED was commanded through a Mightex-universal LED controller (www.mightexsystems.com) able to produce square-shaped functions of variable frequency and duty-cycle. The duty-cycle was fixed to 0.5 so that the durations of on and off periods are equal. The LEDs were shone through a diffusion screen. The subjects sat at about 100 cm from the LED panel.

The EEG was acquired using a TMSi Porti amplifier (www.tmsi.com) at a sampling rate of 2048Hz. The signals from 20 electrodes: Fp1, Fp2, F7, F3, F4, F8, T3, C3, C4, T4, T5, P3, Pz, P4, T6, PO3, PO4, O1, Oz, and O2 referenced to Cz were recorded. Cz was chosen as reference to mimic the operation of a future convenient cap for BCI, which records signals from occipital sites only, and referenced to Cz. Subjects were requested to try avoiding eye blinks and movements during LED stimulation. The presence of artefacts was visually checked so as to ensure that the training epochs were artefact-free.

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A thirty-minute session consisted of four recordings, one per stimulation frequency. In each recording, subjects were asked to look at a particular LED flickering at the recording's targeted frequency. During a recording, five-second long stimulation periods (all four LEDs on) were followed by break periods (where all the LEDs are switched off) of random duration between three and five seconds. Each recording comprised twelve stimulation periods. The sequence of frequencies is randomised.

VII. Results of Evaluation

The first evaluation aimed at a proof of concept of the integrated system and the HF-SSVEP BCI paradigm. In addition to evaluations in Telefonica on 15 subjects, evaluations were performed at the UU using a smaller number of able-bodied subjects and the lead user. At this point a structured evaluation was not undertaken; however the following observations have been obtained.

Recording of EEG: An experienced EEG technician undertook the recordings at UU. This was important as her skill of interacting with subjects put them at their ease. In particular, she was able to explain all of the procedure that could potentially cause anxiety, e.g., the use of gel for skin contact and the need to apply this with a syringe and blunt applicator. The application and achieving of good electrode contact and electrode removal were hence simplified.

Electrodes and cap – the users' experience: The application of electrodes did not provide significant discomfort to the participants. The use of a cap helps determine the location for the electrodes. However when recording from a number of electrodes simultaneously, difficulty can arise if contact is lost for any of the electrodes - causing the average reference to be skewed. For EEG technicians the application of a small number of electrodes 6-8 over the occipital region is much easier to achieve by direct application. This requires accurate mark-up for electrode placement, but is straight-forward and quick for an EEG technician. For a carer, accurate direct application of electrodes would be much more difficult. Thus it appears that a 'scaled down' version of the cap is required. This should have a reduced number of electrodes but be easily applied in a domestic setting.

The use of high frequency LED stimulation did not pose any perceptual or practical difficulty to the participants. Performance was variable across the group and seems to be personalised. Light contrast was not perfect in the recording room, but this mirrors the environment in which BCI is intended to be used in this project. There was no indication that BCI performance was worse in the Cedar tenant. This provides some optimism for the use of HF-SSVEP in a domestic setting.

Recommendations: A trained EEG technician should be used with Cedar tenants for subsequent recordings. A smaller more aesthetically appealing and practical cap is required.

Preliminary Evaluation results: For each recording a spatial filter was determined. Receiving Operator Characteristic (ROC) values were calculated giving a representation of the accuracy of the paradigm. Values as high as 97.4 were reached, but ranged significantly from subject to subject. More extensive user high frequency calibration EEG recordings are currently underway within UU on both able-bodied subjects and the lead user.

VIII. Lead User

One primary lead user was identified and invited to take part in the meetings of the local consortium and full consortium meetings at the Belfast site held during March 2009. General information about the project was shared at this meeting, in addition to outlining the proposed methodology and process of consent. A video about BCI was shown to potential participants and their formal carers. This meeting took place within the supported living scheme of the Cedar Foundation. Staff from UU were in attendance to respond to questions and demonstrate a BCI cap.

Below gives a statement from the lead user on his involvement within the project:

I was approached about being a "lead user" in this project because my personal situation and circumstances put me in a unique position that enables me to view the ongoing research we are engaged in with very novel and valuable insight. Some years ago I was very severely hurt in a sporting accident. As a result I now use a wheelchair, my right arm is paralysed, and I am dysarthric (slurred speech). But despite being severely physically disabled, my higher brain function is fine, and I managed to get a B Sc Hons in computing. So my disability lets me see things from a user point of view, but I also have a comparable level of technical knowledge to the researchers.

For example, I know first hand what "locked-in syndrome" feels like, as I was "locked-in" for 6-8 months immediately after my injury. It is even more significant that, prior to my injury, I was training to be a doctor. This means I have good "technical" knowledge of the brain itself, as well as enhanced knowledge about other kinds of medical user. The combined outcome of all of this makes me well-fitted to be a "lead user" on this project. I hope to enrich it considerably, as it is a subject very close to my heart.

The lead user is an informed candidate with excellent technical knowledge. In addition to valuable and technically pertinent guidance on user requirements, he has been instrumental in bridging the gap between evaluations using able-bodied subjects and full evaluation on disabled Cedar tenants. From this involvement we can quickly respond to elementary design issues, and he has also guided us in the development of structured evaluations.

IX. Results

From the Cedar workshop and the questionnaire user requirements were obtained. In terms of physical requirements, all participants are wheelchair users with a range of seating postures and positions. It is important therefore to establish the acceptable working distance of the individual when wearing the BCI cap in relation to the device that will house the system. All participants require significant assistance from care staff for activities of daily living. Assistance will be required to fit the cap during much if not all of the development.

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A practical requirement is that training and support for participants is important due to limited exposure to devices and systems to date.

In terms of user preferences, communication is the prime function users wish to try, although using the system to support phone calls was not well received. Accessing multimedia content is of interest. Television is an important entertainment device to participants, and integration of the BCI software into the television or vice versa may support access and usage.

All the participants were supportive of the BCI development and could visualise the potential of the system to enable engagement and participation. All those interviewed were very positive about the project, and motivated to be part of the BRAIN project.

From the Telefonica workshops and questionnaire further user requirements were obtained. The users expressed desire for an entertainment system which is able to manage multimedia formats, and whose content can be stored in any media server integrated in the home network.

Interoperable systems are desired. The system should support the control of many devices, from media players and servers, to home-based devices/sensors, and communication devices, all coming from different technology areas. Communication capacities are requested. In case of people who need special care, this is considered essential. The television is one of the most valued devices to be controlled by BCI system. The context of environmental information should be taken into account to handle smart services.

The BCI system is considered by users as a possible 'remote control' to access to home applications. For a skilled BCI user, this could be a simple task. However some aspects concerning BCI interaction should be improved according to users' opinion. Techniques to make training easy are requested. The majority remarked that improvements of graphical interfaces are needed to make them more usable.

This work has influenced the design of the IGUI leading it to be implemented on a multimedia workstation which could also function as a television and communication device.

Testing has been carried out to ensure that the IGUI can interact with the BCI system and home-based applications. Extensive IGUI unit testing of menu operation and the ability to issue a command has been completed. Integration testing of the IGUI has been successful concerning: demonstration of the correct traversal of the IGUI menu via mouse operation (needed for additional control by carers), successful connection of BCI2000 and devices via UAI. A Universal Plug and Play (UPnP) light emulator was implemented for integration testing. Initial supported devices include UPnP PowerSwitch service and wireless X10 controller. New devices are easily supported by means of a UPnP wrapper around the native Application Programming Interface (API).

Initial testing with subjects indicates that the HF-SSVEP paradigm is feasible in the research laboratory. However, it is necessary to calibrate frequencies for each subject under test and work is underway on a software wizard to facilitate this process. At present, interface metrics regarding usability in the two target groups still have to be collected.

X. Discussion and Conclusions

The user interface uses a 4 way interaction: left, right, up, down. These commands have been mapped onto BCI commands. Currently menu items are grouped by space and function in order to ease identification and selection. These groupings can be adjusted within an XML declaration in order to balance depth and breadth of navigation, to facilitate the accessibility of final commands by reducing the number of menu navigation steps required to reach them. Primary grouping is made by the rooms associated with the users' housing environment: living room, bedroom, hall etc. and then by function: lighting, television, heating. An additional classification of menu item 'Sticky' is also used to ensure that significant applications such as a Speller, or the ability to answer the door or phone are always available.

The environment to deploy UAI applications as web services has been set up under the OSGi framework Equinox. UAI applications are implemented as OSGi bundles that are easily installable in the system. The UAI is able to filter the discovered UPnP devices so that only authorised devices are operated by the BRAIN system. The software light emulator and light control application has been successfully tested, and indicate the potential for more complex home-based device interaction. Additional user trials will allow us to collect information which can then be used to impart intelligence into the menu structure. This can improve the effective bit rate of the BCI.

The IGUI is intuitive and can be personalised. The menu is based on photographs of the intended location/device, which may be personalised to the specific environment, and so should be intuitive in use. It does not rely on literacy. The size of the menu could be scaled, appropriate to poor visual acuity. The menu structure may be easily extended for further rooms and devices. Each device can have additional menus appropriate to the complexity of operation, e.g., a media player will have more controls than a simple switch.

Interaction with the UAI is via web services, and a queue of current events. IGUI and devices can communicate with this queue to indicate their current state, e.g., turn a light off, if already on. Communication with the BCI is via UDP network packets. This provides a decoupling of technologies, enabling independent development (e.g., BCI2000 has been developed in C++, whereas the IGUI has been developed in JAVA). This provides an IGUI which is potentially open to the wider community for enhancement.

We are in the process of implementing a BCI system for use outside of the laboratory. Initial testing has occurred inside the laboratory, and hence our overall rationale still requires appropriate validation by end-users. However our design will allow us to deploy a BCI system to deliver a number of services, which the users desire and with familiar control using a consistent extendable (and in the future) context aware intelligent IGUI.

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With developments in all aspects of BCI it can be envisaged that there will come a time when such devices will become accepted by users and society [20]. Already advances are starting to show how BCI headsets could become quite acceptable to wear and gaming research and market has delivered some interesting results and products [21]-[24].

This is an example of pervasive computing, an emerging research area where sensors and computers support people in their home or work environments. In these environments, it is highly desirable that the systems and services must be able to adapt and react without the need for people to intervene to configure them, the concept of calm computing [25].

Employing a user-centred design approach has added value and direction to our development, and value to the project outcomes overall. We have employed three types of user profile:

Larger scale evaluation using healthy non-disabled users: Providing us with exhaustive system and unit testing, in addition to experiential feedback.

Smaller scale evaluation using suitable disabled users with diverse needs: Providing us with representative user involvement that can highlight design issues and user needs as well as experiential feedback.

Lead user: Bridging the gap between non-disabled and disabled users as well as between the disabled users and the developers. This enables user feedback to be incorporated at an early stage and during development before rolling out full scale evaluations.

The model of user involvement and the concept of a lead user provides a sound structure from which to develop a user friendly and robust BCI system for domestic environments.

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REFERENCES

[1] Harnessing The Power Of The Brain, CBS news.com, "60 minutes", http://www.cbsnews.com/stories/2008/10/31/60minutes/main4560940.shtml, accessed Oct 2009.

[2] Wolpaw JR, Birbaumer N, McFarland FJ, Pfurtscheller G, Vaughan TM, Brain-computer interfaces for communication and control Clinical Neurophysiology, Vol. 113, No. 6, 767-791, June 2002.

[3] Allison BZ, Wolpaw EW, Wolpaw AR. Brain-computer interface systems: progress and prospects. Expert review of medical devices 2007 4(4), 463-474

[4] Mason S. G, Bashashati A, Fatourechi M, Navarro K. F, Birch G. E, 'A Comprehensive Survey of Brain Interface Technology Designs', Annuals of Biomedical Engineering, Vol 35, No. 2, Feb 2007 137-169.

[5] Anton Nijholt, BCI for Games: A 'State of the Art' Survey, Springer Berlin / Heidelberg, Lecture Notes in Computer Science, 2009.

[6] Allison BZ, Wolpaw EW, Wolpaw AR. Brain-computer interface systems: progress and prospects. Expert review of medical devices 2007 4(4), 463-474.

[7] BCIs with Rapid Automated Interfaces for Nonexperts (BRAIN, FP7-ICT-2007-2, Project number 224156), https://www.brain-project.org/, accessed Oct 2009.

[8] Von Hippel, E., "Lead Users: A Source of Novel Product Concepts," Management Science, 32, 791-805, 1986.

[9] B. Achilladelis, A.B. Robertson, and P. Jervis, Project SAPPHO: A Study of Success and Failure in Industrial Innovation, 2 vols. (London: Center for the Study of Industrial Innovation, 1971).

[10] Allison. The I of BCIs: Next Generation Interfaces for Brain–Computer Interface Systems That Adapt to Individual Users in: Human-Computer Interaction. Novel Interaction Methods and Techniques, Lecture Notes in Computer Science, Springer Berlin / Heidelberg, 2009.

[11] Garcia Molina, G., David Ibañez, Mihajlovic V, and Chestakov D. Spatial filters for Detecting Steady State Visual Evoked Potentials Journal Biomedizinische Technik / Biomedical Engineering, 2009.

[12] Durka P, Kus R, Zygierewicz J, Milanowski P and Garcia G, 'High-frequency SSVEP responses parametrized by multichannel matching pursuit', Frontiers in Neuroinformatics. Conference Abstract: 2nd INCF Congress of Neuroinformatics. 2009.

[13] The Cedar Foundation, http://www.cedar-foundation.org/ last accessed February 2010.

[14] BrainGain, http://www.nici.ru.nl/cgi-brain/index.cgi?page=index;lang=en last accessed January 2010.

[15] Bayliss J.D, "Use of the Evoked Potential P3 Component for Control in a Virtual Apartment", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 11(2), 113-116, 2003.

[16] C.Neuper, G.Müller, A.Kübler, N.Birbaumer, G.Pfurtscheller, 'EEG-based brain–computer interface: a case study in a patient with severe motor impairment', *Clinical Neurophysiology*, Volume 114, Issue 3, Pages 399-409, 2003.

[17] A. Vuckovic, 'Non-invasive BCI: How far can we get with motor imagination?' *Clinical Neurophysiology*, Volume 120, Issue 8, Pages 1422-1423, 2009.

[18] B. Allison, I. Volosyak, T. Lüth, D. Valbuena, I. Sugiarto, M. A. Spiegel, A. Teymourian, I.S. Condro, A. Brindusescu, K. Stenzel, H. Cecotti and A. Gräser: "BCI Demographics: How many (and what kinds of) people can use an SSVEP BCI?"; in Proc. 4th International Brain-computer Interface Workshop and Training Course; 2008; Graz, Austria, Sep. 18-21, pp. 333-338..

[19] Schalk G, McFarland D. J, Hinterberger T, Birbaumer N, Wolpaw J. R, 'BCI2000: A General-Purpose Brain-Computer Interface (BCI) System', IEEE Trans. On Biomedical Engineering, 51(6,) 1034-1043, June 2004.

[20] Rod Furlan, Igniting a brain-computer interface revolution – BCI X Prize, http://singularityhub.com/2010/01/21/igniting-a-brain-computer-interface-revolution-bci-x-prize/, January 21st, 2010, last accessed 24th February 2010

[21] Emotiv company website, http://www.emotiv.com/ last accessed 24th February 2010.

[22] Neurosky company website, http://company.neurosky.com/partners/ last accessed 24th February 2010.

[23] M. Tangermann, Games and Entertainment in BCI, Integrating Brain-Computer Interfaces with Conventional Assistive Technology. TOBI Workshop 2010

[24] Nijholt A, BCI for Games: A 'State of the Art' Survey, Entertainment Computing - ICEC 2008, Lecture Notes in Computer Science, Springer Berlin / Heidelberg, Volume 5309, Pages 225-228, 2009

[25] Weiser M., "The Computer for the 21st Century," Scientific American, Vol. 265, No. 3, 1991.

Digital Object Identifier: 10.4108/ICST.PERVASIVEHEALTH2010.8888
http://dx.doi.org/10.4108/ICST.PERVASIVEHEALTH2010.8888