Context-Awareness as an Enhancement of Brain-Computer Interfaces

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Abstract. Ambient intelligence has acquired a relevant presence in assistive technologies. Context-awareness, the ability to perceive situations and to act providing suitable responses, plays a key role in such presence. BrainAble, an ongoing European project, aims at raising the autonomy of people with functional diversity, facilitating and enhancing the interaction with their environment. Brain-computer interfaces are applied as communication means to allow users to perform actions by using their electroencephalogram signals. Multiple approaches are studied and combined in order to provide the best set of brain signals which specifies a concrete event or action. In this setting, we propose the application of context-awareness to extend the traditional proactive and pervasive nature of ambient intelligence in a way which enhances the brain-computer interface. One practical example is the dynamic personalization of available options in the user interface, based on user's current context.

Keywords: Assisted Living, Brain-Computer Interfaces, Context-Awareness, Contextual Facilitation

1 Introduction

Ambient intelligence (AmI) has introduced a new source of potential applications and services with a promising impact on assistive technologies. The role of AmI is generally related to the home automation or control of ubiquitous devices in the environment. However, the AmI feature that provides the most benefits in terms of assistance to the users is its context-awareness, which, in the case of assistive technologies, refers to the recognition of situations and acting according to the level of assistance required.

Systems that can represent and process information about context can address special requirements of the ageing society and people with functional diversity, and can personalize tasks and support software-tools according to the needs and situations of each individual. Thus, AmI could assist people with functional diversity in their daily life to improve their autonomy and living conditions. Approaches that rely on this type of technology to accomplish assistive tasks have been mainly focused on the monitoring and recognition of *activities of daily life* (ADLs). For example, one approach detects complex human activities from a continuous sequence of events to prevent emergencies [1]. Another example is the implementation of a multi-agent architecture (connecting healthcare institutions, patients and their relatives on a common network) for monitoring and recognizing specific situations [2]. Similarly, a rehabilitation approach was designed to provide users with topographical disorientation with adaptive tools and feedback based on their own actions [3].

Brainable, an ongoing project funded by the European Commission (FP7 grant agreement n° 247447), aims to improve quality of life among people with functional diversities by overcoming two of the main shortcomings they suffer: exclusion from home activities and social activities. The main objectives are therefore the enhancement of their autonomy and independency for ADLs, and the improvement of their social inclusion. Within the project, the achievement of these objectives strongly relies on the use of *brain-computer interfaces* (BCIs), which are systems that allow communication and control via thought alone [4] [5] [6]. They are based on the direct measures of brain activity and are employed in conjunction with other technologies such as AmI, social networking and virtual reality. Thereby, users are empowered to take actions or express their desires in the form of decisions selected from a set of options supplied by a user interface.

The role of AmI over the provision of control capabilities to the user is mainly to carry out the interaction with the real environment by performing the user’s commands (e.g., to turn on a light). In addition, an unobtrusive network of pervasive devices acts to proactively manage emergency, security, comfort or energy-saving issues. Thanks to context-awareness, specific situations are recognized and suitable responses are performed.

A number of BCI approaches have been heavily researched and rely on different recording methods, modes of operation and mental strategies to obtain specific patterns of activity. In any case, they are limited and cannot compete with natural communications or traditional human-computer interfaces in most situations [7]. In this paper, we address issues in incorporating context-awareness to enhance BCI performance. Thus, considering this type of aid as a contextual facilitation, it could be stated that if BCI is a bottom-up, stimulus-driven perceptual mechanism, then context is its top-down inference complement.

The remainder of the paper, Sections 2 and 3, provide a background for the Brainable project, as well as the features and constraints of BCI. Section 4 introduces context-awareness as an enhancement of BCI and its corresponding benefits for the user, and Section 5 describes the architecture and its implementation in the first prototype of the Brainable platform. This is followed by a description of future work and some concluding remarks.

2 The Brainable Project

It is known that motor functional diversity of any source have a dramatic effect on people’s quality of life. The Brainable project addresses this problem from several perspectives. It conceives, researches, designs, implements and validates a *human-*

computer interface (HCI) composed of BCI sensors combined with affective computing. These technologies aim at improving the quality of life of people suffering from functional diversity by addressing their two major limitations: exclusion from home and social activities. Brainable operates in the inner world for functional independence for ADLs and in the outer world for social inclusion. The project's platform helps then people with functional diversity manage their living environment and improve social interaction.

Objectives of Brainable's user-centric platform are: (1) to improve the quality of life of people with motor functional diversity, (2) to increase autonomy in ADLs and social inclusion, (3) to decrease communication barriers, (4) to create a specifically designed HCI, which integrates BCI with other specific sensor technologies, (5) to build user-centric virtual environments for home and urban automation control, social networking and training, (6) to create AmI and ubiquitous-computing services for accessible device integration, by adapting a *universal remote console* (URC) / UCH standard platform and (7) to investigate self-expression media, VR-based tools and social networking services in relation to BCIs.

Brainable expects to build and test a product prototype and a set of associated technologies intended to assist people with physical functional diversity ranging from speech disorders to *motor neuron disease* to *locked-in syndrome*. It will facilitate the management of networks of interoperable devices and the access to computer-based social networks for better inclusion.

3 Brain-Computer Interfaces

A BCI is a novel means of communication. Sometimes called a *direct neural interface* or a *brain-machine interface*, it is a direct communication pathway between a human brain and an external device. In Brainable, BCI development is based on the non-invasive electroencephalogram (EEG). EEG signals are potential differences recorded from electrodes placed on the scalp and reflect the temporal and spatial summation of electrical inputs to large groups of neurons lying beneath the recording electrode. BCIs have a very limited bandwidth and cannot compete with other means such as speaking, writing or traditional HCIs [7], but can be extremely useful for users who cannot speak, write or use traditional HCIs. The main problem with BCIs is the poor *information transfer rate* (ITR), which is the amount of information a user can send in a certain interval, and is expressed in bits per units of time. ITR may be used to measure performance in BCIs or other communication systems, and relies on three factors: the number of available signals or commands (N), the accuracy in classifying the desired signal (P), and the number of signals per minute (S) [4].

Early BCI research efforts focused primarily on proving that a system could work, and then on validating BCIs with patients and field settings. While these are critical goals, early work did not consider how to incorporate context. That is, a BCI signal was translated into a message or command regardless of contextual information such as recent commands, available options, or the state of the user or system.

This has begun to change, with increasing attention to goal-oriented protocols and context-aware BCIs in more recent work [6] [8]. Thus by adding contextual information could increase the effective ITR of a BCI by allowing users to accomplish their goals more quickly and effectively. A system that only allows a user to convey 10 bits per minute may be quite adequate for many needs if the user does not need to painstakingly communicate unnecessary details.

4 Contextual Facilitation

In Brainable, BCI communication acquires an especially significant importance, because it enables people with severe functional diversities to interact with their environment. As mentioned above, considering its limitations, BCI performance may be enhanced by using context-awareness as complement. To better understand this complementarity, let us consider the analogy of language processing, which is also strongly influenced by context. According to the two major psycholinguistic hypotheses which analyse the linguistic interplay, there are two distinct mechanisms: a bottom-up one, sensitive to linguistic information and a top-down one, sensitive to contextual knowledge [9]. According to the Gradient Salience hypothesis [10], these two mechanisms run in parallel and interact in order to foster language comprehension. A related comparison was explored in [8]. In this paper, Wolpaw noted that the human body relies on top-down, high level processes and bottom-up, low-level processes. People may decide to get a glass of water, and then initiate a process with many low-level details that are not consciously processed. People do not think about how exactly to move their legs or coordinate visual stimuli (such as the location of a glass) with motor activity (such as pouring into the glass). The paper notes that BCIs should be similar. BCI users should not have to inform a robotic arm of all the necessary movement details. Instead, BCI users should be able to send one high-level command, such as “get water”, and rely on the software to manage the lower-level details. Ideally, users should be presented with both high-level and low-level commands, so they can attain goals quickly if desired, but can also change medium or low-level details (such as getting juice instead of water, using a different cup, or avoiding the use of one finger that is injured.

Contextual facilitation may be therefore a complementary expectation-driven mechanism, which improves BCI performance by predicting oncoming events and by constraining and personalising possible options for the user to select. Two of the main research approaches to be applied in the Brainable project are the BCI improvement by personalization and by inference. Personalization refers to the dynamic presentation of the most convenient options to select from the user interface based on the current context, while inference refers to the presentation of predicted options based on user’s preferences under a determined context.

Personalization could be useful in various contexts. In a smart home environment, a context aware system might know that a door is open, and thus would not present the user with the option of opening that door. In a smart home or VR environment, if a wheelchair, mobile robot, or virtual avatar is in front of a wall or other obstacle, then the option to move forward should not be available to the user [6] [8].

5 BrainAble’s AmI Centric Architecture

Brainable is designed with a centralized modular architecture around the Ambient Intelligence (AmI) module.. Fig. 1 shows a high level block diagram of the modules. It is composed of 5 modules: *BCI Module, VR Module, Weather Sensors, UCH Module, AmI Module*. Communication paths are shown as uni or bidirectional arrows and all communication paths in Brainable need to pass through the AmI Module.

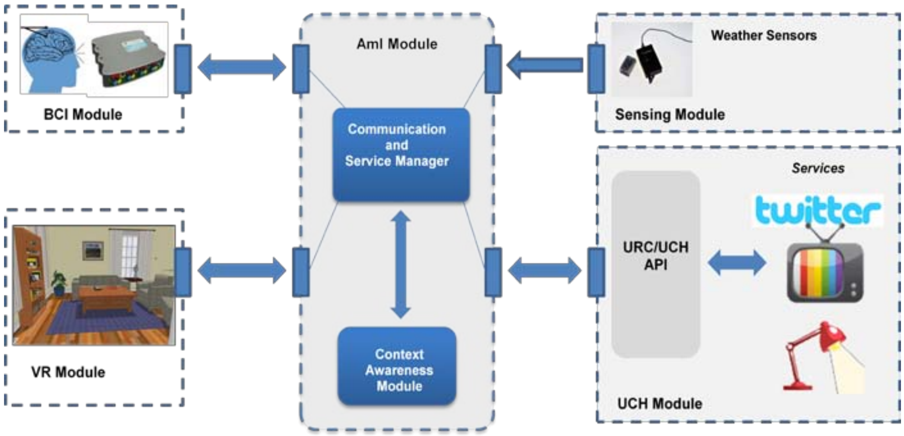

Fig. 1. Brainable centralized architecture consisting of 5 modules: *BCI Module, VR Module, Weather Sensors, UCH Module, AmI Module*

BCI Module Contains the BCI processing logic, hardware, and GUI to transform the user's brain signals into an action or command to be executed. The BCI actions are accessed via a hierarchical menu that is visually presented to the user. For example the user must select using the BCI "Devices then TV then Channel 5" in order to execute the command that changes the channel on the television. The platform has been implemented with two BCI GUIs, the P300 Matrix [11] and Hex-o-Select [12]. Selection in the BCI menu takes time, and selection of an action item takes even longer if it is embedded deep within the menu. Providing a context sensitive shortcut area in the BCI that is sensitive to context can reduce the number of selection considerably.

Sensing Module In order to gather useful contextual information, the sensing module will provide access to environmental and physiological sensors. Currently the room temperature, luminosity and humidity are being captured.

UCH Module The Universal Control Hub is a middleware to provide a uniform and consistent API to all devices and services via a HTTP protocol gateway. Devices can be attached to the UCH and their status and control are available via the gateway.

VR Module Brainable provides a virtually interactive environment for training a new user to the platform, and also for providing an enhanced experience. The user is represented by a virtual avatar and is able to navigate the virtual environment.

AmI Module All commands issued by the BCI pass through the AmI Module, and the sensor information also is relayed to this module. By continuous use of the system the AmI Module is able to learn the user's personal habits by a Bayesian based algorithm described later in the section. When a similar context arises, that is similar to one seen before, the AmI Module is able to provide back to the BCI a list of probabilities of the most likely actions. Using this list the BCI is able to provide through an adaptive shortcut area direct access to the action, saving the user time spent by navigating through the hierarchical menu.

Services in Brainable prototype

In the first prototype the limited services included are listed in Table 1 along with the corresponding actions that are selectable in the BCI menu.

Table 1. Table of services with actions offered in Brainable prototype.

Service Type	Service	Actions
Domotic device	Light	On, Off
	TV	On, Off, Set Channel (1..5), Volume Up, Volume Down
Social	Twitter	Log On, Log Off Send Tweet, Get Tweets

Context

Context in [13] is defined as any information that can be used to characterize the situation of an entity. In Brainable it is captured by a list of Boolean, and numeric descriptors that are gathered via the sensors (temperature, humidity, luminosity), the service states (light, tv, twitter login status) and the current time (day of the week, hour of the day, season).

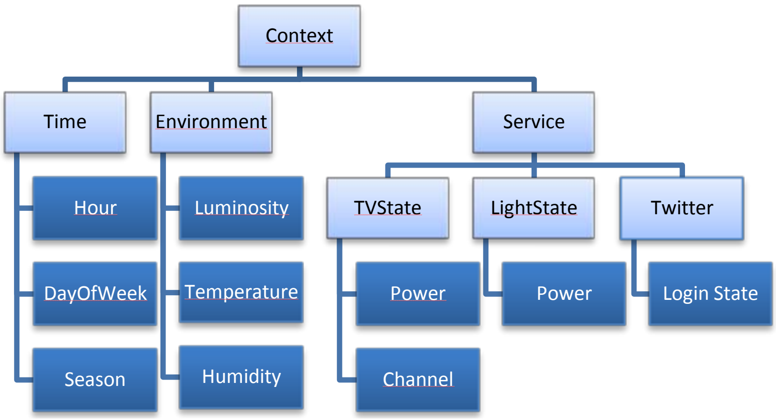

Fig. 2. Context consists of a set of descriptors (leaf nodes) from time, environment sensors and service status.

These inputs are shown in Fig. 2 as the leaf nodes, the upper nodes reveal the category the context descriptor belongs to. The descriptors allow the AmI Module to characterize a particular situation, for example: it is late at night on the weekend, and the user is watching TV, on channel 4, while the light is turned off. In the next section we present how using a Bayesian approach the AmI Module can learn to anticipate action from the context.

Learning from Context

In order to address the slow selection speed of the BCI we proposed to use the user's context to anticipate the most likely actions, furthermore these actions could be presented in an adaptive shortcut area of the BCI menu so that the user does not have to waste time by navigating through the menu hierarchy, instead the action is available more directly in the shortcut area available at all times in the BCI GUI.

An effective and well studied Bayesian classifier is Naive Bayes [14]. It is capable of estimating probabilities for classes after training with a set of features, and has already proved effective in context classification from sensor based networks [15]. In our case, we use this method to obtain an estimate for $P(A \mid Context)$ where A is an actions listed in Table 1 and $Context = \{X_1,X_2,X_3...X_n\}$ are the context descriptors of Fig. 2. The context descriptors that are continuous, such as luminosity, are quantized into a discrete number of values so that statistics can be counted. Finally the probability can then be estimated using the Bayes rule and the statistical independent naive assumption:

$$P(A|X_1,X_2,X_3...X_n) = P(A)\ P(X_1|A)\ P(X_2|A)\ ...\ P(X_n|A)\ Z \qquad (\mathbf{1})$$

Where $P(A)$ and $P(X_i|A)$ represent the prior probability, and conditional probability, both calculated during training, and Z is the normalizing factor.

Training occurs automatically and is personalized to the user by the continued use of the Brainable system. All commands are routed through the AmI Module and it keeps a record of statistics in histograms of each action against each context descriptor in order to calculate the conditional probabilities $P(X_i|A)$ needed. Eventually the system will capture patterns that emerge about the user's personal habits. For example the user turns on the light everyday when the luminosity falls below a certain value, or the user turns on the TV on weekends at 8pm. The next time this context is encountered the adaptive BCI interface will offer the appropriate action directly as equation (1) will produce a high probability for these actions.

7 Conclusions and future work

The Brainable project is in an early stage where a first integration of technologies to satisfy user requirements has resulted in a 1st Year Prototype. Validating the ideas in the Brainable project requires additional development, implementation, testing, and revision. The Brainable consortium plans to study and assess different BCI mental strategies and their combination with other physiological signals to assess their feasibility. There are different options on how to apply contextual facilitation. This paper presented some possibilities, but some other options are also worth exploring. In addition, context awareness presents different challenges across different input signals, users, devices, applications, and environments. The objective is to assess and learn from these early approaches in order to improve and implement these innovative ideas on suitable assisting services.

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