

# The ASPICE Project: Inclusive design for the motor disabled

F. Aloise<sup>1,2</sup>, F. Cincotti<sup>1</sup>, F. Babiloni<sup>1,3</sup>, M. G. Marciani<sup>1,4</sup>, D. Morelli<sup>1</sup>, S. Paolucci<sup>1</sup>, G. Oriolo<sup>5</sup>,  
A. Cherubini<sup>5</sup>, F. Sciarra<sup>6</sup>, F. Mangiola<sup>6</sup>, A. Melpignano<sup>7</sup>, F. Davide<sup>7</sup>, D. Mattia<sup>1</sup>

<sup>1</sup>Fondazione Santa Lucia IRCCS,  
Roma, Italy

<sup>3</sup>Dip. di Fisiologia Umana, Univ. "La  
Sapienza", Roma, Italy;

<sup>6</sup>Unione Italiana Lotta alla Distrofia  
Muscolare, Sezione del Lazio,  
Roma, Italy;

<sup>2</sup>Dip. di Elettronica, Informatica e  
Sistemistica, Univ. della Calabria,  
Rende (CS), Italy

<sup>4</sup>Dip. di Neuroscienze, Univ. "Tor  
Vergata", Roma, Italy;

<sup>7</sup>Telecom Italia Learning Services,  
Roma, Italy

<sup>5</sup>Dip. di Informatica e Sistemistica,  
Univ. "La Sapienza", Roma, Italy

## ABSTRACT

The ASPICE project aims at the development of a system which allows the neuromotor disabled persons to improve or recover their mobility (directly or by emulation) and communication within the surrounding environment. The system pivots around a software controller running on a personal computer, which offers a proper interface to communicate through input interfaces matched with the individual's residual abilities.

This system links to the concept of user-centered interface promoted by human-computer interaction researchers. Each person has a "singular disability", thus the system must provide the possibility to use an adaptive interface customized to their own ability and requirements, which stem from contingent factors or simple preferences, depending on the user and his or her life stage, task, and environment.

At this time, the system is under clinical validation, that will provide assessment through patients' feedback and guidelines for customized system installation.

## Categories and Subject Descriptors

H.5.2 [User Interfaces]: *Graphical user interfaces (GUI) Input devices and strategies*. K.4.2 [Social Issues]: *Assistive technologies for persons with disabilities*. I.2.9 [Robotics]: *Commercial robots and applications*.

## Keywords

Technologies for Independent Life, Brain-Computer Interfaces, Robotic Navigation, Ambient Intelligence, Severe Motor Impairment.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

Conference '04, Month 1-2, 2004, City, State, Country.  
Copyright 2004 ACM 1-58113-000-0/00/0004...\$5.00.

## 1. INTRODUCTION

The ultimate objective of medical care or treatment is the recover from the disease, or alternatively the improvement of the clinical symptomatology proper of the disease. In the field of rehabilitation, the main goal is the reduction of the disability provoked by any pathological condition that is the achievement of the maximum independence for a given clinical frame, by means of orthosis and the management of the disability related to the social disadvantage by means of different types of aids.

Recently, the growing evidence for the development of electronic devices capable of ameliorating the possibility to increase the communication and the management of the house-environment has opened new avenues for patients affected by severe movement disorders with preserved cognitive functions. These devices still suffer from limitations due to the necessity of a residual motor ability which might prevent some pathological condition from their use.

It exists today the knowledge to convey a cutting edge technological and scientific result in a way that the largest part of the population can benefit from it.

The project offered the opportunity to integrate the technologies described in the three sections below, to develop the awareness of a possible application in every day's life, with particular attention to people who suffer from diseases that affect their mobility.

### 1.1 Brain-Computer Interfaces

"Brain-computer interfaces (BCI's) give their users communication and control channels that do not depend on the brain's normal output channels of peripheral nerves and muscles."; "A BCI changes the electrophysiological signals from mere reflections of Central Nervous System activity into the intended product of the activity: messages and commands that act on the world"[1].

A non-invasive BCI is made up by a electroencephalographic (EEG) recording device that gives access to brain electrical activity; these raw signals are processed and transformed to

---

Corresponding author, Febo Cincotti, Fondazione Santa Lucia IRCCS,  
via Ardeatina 306, I-00179 Roma, Italy. febo.cincotti@uniroma1.it

extract relevant features which are then passed on to some mathematical models (in principle, neural networks). After both the subject and the artificial classifier have undergone a training process, this model translates the appropriate mental commands to control a cursor on a screen or, if appropriately connected, an external device.

Experience on BCI technology has been gathered in the last 20 years on BCI's based on variations of EEG rhythmic activity, capturing the signals by means of an electrode cap to control the movement of a cursor on a computer screen [2]- [3]. The research group in Albany, New York State, has disseminated their knowledge in the field also in form of a PC program that implements the necessary algorithms for the training [5]. The BCI technologies have been applied as an aid to individuals with a severe motor disability; in this respect the Tuebingen group in Germany has the longest experience [6]. Typical applications of this technology are letter spellers. The Graz group also demonstrated the ability of BCI's to open and close a hand orthosis [6]. Recent experiments provided demonstration of non-invasive BCI's use to directly control the movement of cursors or simple robots in real time [7],[8].

## 1.2 Robotics

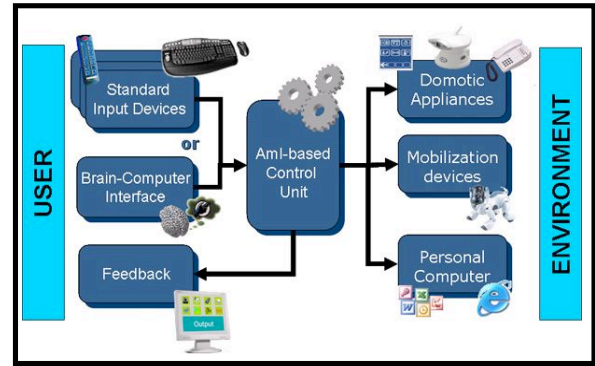
The possibility of taking advantage of robotic technologies in the present research project stems from the fact that, in the last decades, the morphology of robots has undergone a remarkable mutation: from the fixed-base industrial manipulator, it has evolved into a variety of mechanical structures, characterized by the fact that the robot is capable of locomotion. This ability has largely increased the domain of application of robots, once limited to the traditional factory environment, encompassing a number of different situations, including material and goods transportation, assistance to hospital patients and disabled people, space exploration and many others

Navigation systems for sensor-based robot motion have made impressive advancements in recent years. Along the way, it has been necessary to address a number of theoretical and technological issues, such as: perception, self-localization, obstacle avoidance, motion planning, motion control.[9]-[10]

While solutions are available for all the above problems, there is a gap to be filled concerning the application envisaged in the present project. In fact, the limited set of low-rate, high-level commands received from the user through the BCI must be integrated by an intelligence layer so as guarantee safe and efficient and task execution.

## 2. DOMOTICS

Most homes today have appliances that allow for some degree of remote control - TV and hi-fi sets, air conditioning, alarm, etc. Domotics integrates and extends this ability throughout the house. A house with a domotics system probably will have at least one computer that will allow the homeowner to control different applications in various parts of the house remotely. A house that is equipped with a domotic system likely will have the ability to call the police or fire department by itself, unlike normal alarm systems. Domotic systems are often able to automatically gather data from several sensors and perform such things as adjusting lights, pull back curtains and lift window blinds without physical interaction. Also, the user can open and unlock or lock doors and gates remotely, control indoor temperature, set lights to go off, and doors to lock--all with a touch of a button. With a domotic



**Fig. 1 Outline of the architecture of the ASPICE project. The figure shows that the system interfaces the user to the surrounding environment.**

system, you can even have your PC screen or TV set act as a home monitoring system, so that if someone is at the front door, you can see who it is without going to it.

Though potentially useful for the disabled, those systems are not always designed to include the needs of this part of the population.

## 3. OVERVIEW OF THE ASPICE PROJECT

The ASPICE project (Assistive System for Patient's Increase of Communication, ambient control and mobility in absence of muscular Effort) has received in 2004 a renewable two-year funding grant from Italian medical research charity foundation TELETHON. The project involves three partners, namely the Clinical Neurophysiopathology Laboratory at the Fondazione Santa Lucia IRCCS, the Robotics Laboratory by the Dipartimento di Informatica e Sistemistica of University of Rome "La Sapienza" and Telecom Italia Learning Services S.p.A.

This project is particularly addressed towards those stages of the disease in which the residual muscular strength, if present, cannot be adequate for the utilization of conventional aids and in those conditions in which practical obstacles or security concerns could prevent a displacement from bed. The reduction of the patients' independence involves a consequent increase of caregiver work load. Nowadays, Information Technology offers the chance to develop devices which, if correctly integrated, allow relief from the described limitations. The aid is being developed by integrating the expertise of the partners of the project. The key elements of the system are:

- 1) interfaces for easy access to computer: mouse, joystick, eye tracker, voice recognition, up to utilization of signals collected directly but non-invasively from Central Nervous System (BCI);
- 2) controllers of intelligent motion devices which can follow complex paths, based on a small set of commands (Robotics);
- 3) information transmission and domotics, establishing an information flow between patient and controlled appliances, minimizing structural modifications of the house (Domotics).

The ASPICE architecture, with its input and output devices, is outlined in Fig. 1.

## 4. ACHIEVEMENTS OF THE PROJECT

At this stage of the project, a prototype of the system has been implemented and is available at the Fondazione Santa Lucia for the validation with patients.

In fact, a three-room space in the hospital has been furnished like a common house, and the actuators of the system have been installed afterwards. Care has been taken to make an installation that would be easily replicable in most houses.

### 4.1 Input Devices

The system input devices are customized on the motor users' residual abilities. In fact users can utilize the aids they are already familiar with, and that have been interfaced to provide a low level input to a more sophisticated assistive device. On the other hand, the variety of input devices provides robustness to the patients' abilities' worsening, which is a typical consequence of degenerative diseases.

The software implementation of this modular attitude benefited from the use of the ICon package [11] ICon is an editor designed to select a set of input devices and connect them to actions into a graphical interactive application. ICon allows physically challenged users to connect alternative input devices and/or configure their interaction techniques according to their needs.

### 4.2 Core Operation

The system core receives the logical signals from the input devices and converts them into commands that can be used to drive the output devices.

At any time, only a subset of commands are made available to the user, depending on the past selections. This subset can be defined statically or dynamically. In the static approach commands are organized hierarchically, grouping together those that have a common meaning (e.g. lighting; appliances in the living room; robot navigation; etc). Dynamic access to command is used to anticipate user choices, either basing on usage statistics, or on the environmental context.

In the static configuration, the system behaves as a "cascaded menu" choice system. A xml initialization file, containing information about the structure is loaded upon login of the user, and is used to feed the Feedback module only with the options available at the moment (i.e. current menu). It will be duty of the Feedback module to choose the most appropriate representation of the available choices (i.e. a text menu, a set of icons, a topographical representation of the commands, etc).

In the dynamic configuration, an intelligent agent tries to learn from use which is the most probable choice that the user will make. This prediction can be made on the basis of (i) frequent sequences (after the user has turned the TV on, he most probably wishes to set the volume level); (ii) time of the day (at the twilight, the "light on" command has a higher probability); (iii) of environmental information (if the temperature is high, the user will probably wish to turn the fan on); (iv) of external events (if someone rings the door bell, almost surely the next commands will be "open the door").

Whenever the user select an action that, rather than changing the internal context of the core (i.e. selects a non-leaf item of the cascaded menu), it instructs the system to undertake a physical action, the Control Unit fulfils the user's demands by sending the appropriate control signals to the output appliances. Drivers are used to offer a homogeneous interface from the Control Unit's

point of view. In some cases, previously existing drivers are utilized for the devices, whereas in other cases (e.g. the robotic platform device) the driver has been designed "ad hoc" for the specific system.

### 4.3 Feedback

The user can select the commands and monitor the system's behaviour through a Graphic Interface. Like all other modules, inter-module communication is transported via TCP/IP socket. This is most important in the case of the Feedback module, because this means that this module can run on a different computer from the one that is running the control unit. While, as mentioned, this is true for all modules, the Feedback can significantly benefit from this, since a lighter and low power computer such as a palmtop PC or even a smart phone can be used to give the subject the feedback he/she needs, while being of minimum burden for the user.

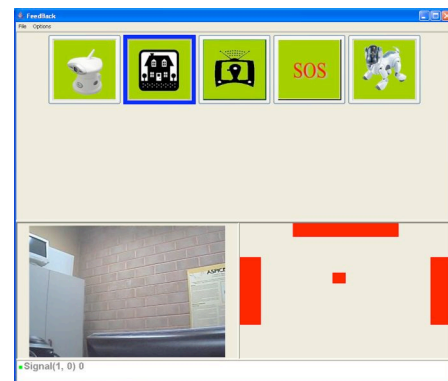
Fig 2 shows a possible appearance of the feedback screen. In this case, choices are pictured as button-shaped icons. This is possibly the most simple interface, and for sure the most practical to be operate with a reduced set of available input signals.

### 4.4 Actuators

The Aspice system allows the user to operate remotely electric devices (e.g. TV, fan, lights) as well as monitoring the environment with remotely controlled videocameras. Moreover, a robotic platform can be controlled from the ASPICE Control Unit in order to accomplish few simple tasks.

While input and feedback signals are carried over a wireless (wifi or Bluetooth) communication, so that mobility of the patient is minimally affected, most of the actuation commands (with the obvious exception of the robot) are carried via a powerline-based control system, namely the X10.

X10 is a communications protocol that uses the house's electrical wiring as the medium for remote control of electrical systems. It was chosen since many components are available at a reasonable



**Fig. 2 Appearance of the feedback screen. Top panel: available selections (commands) appear as icons. Bottom right panel: BCI feedback stimulus. Bottom left panel: video stream from a video camera.**

price, which is an uncommon circumstance for assistive devices.

Moreover, The Robotics Laboratory of University of Rome "La Sapienza" has developed a robot navigation system based on a small set of commands, which has been interfaced with the Aspice system. In fact, as previously mentioned, the system should cope

with a variety of disabilities depending on the patients' conditions. Therefore, three possible navigation systems have been designed for robot control. Firstly, the autonomous mode, which is based on high level commands (e.g. "walk to the window") to drive the robot, should be used by very impaired patients', which are unable to send frequent commands. Alternatively, depending on their residual abilities, patients can use a continuous directional joystick mode with basic obstacle avoidance, or a single step directional joystick to control the robot.

#### 4.5 Clinical utilization

Clinical validation of the prototype has been carried out with the voluntary collaboration of 20 adult subjects affected by motor disability of variable degree due to neuromuscular diseases. The experimentation has taken place at Fondazione Santa Lucia, in the Occupational Therapy facilities, where the prototype is installed. A therapist accompanied the patient during the experimentation. An engineer helped the therapist with technical operations, and took care of customizing the access to the system, according to the needs of each individual. These subjects were asked to interact with the prototype and to provide information about how it was perceived in terms of augmented independence in daily life activity.

The preliminary results indicate that the system can increase the independence of patients. The key aspect seems to be the modularity of its components. In fact, the on-field experience showed how different are the features that individual patients believe be mostly related to their quality of life. The individual's needs and interest must be analyzed and reinforced. Environmental control is a strong positive reinforcement even if the subject partially regains some independency in operating domestic devices. Quantification of these aspects can be obtained only after the end of experimentation

#### 5. CONCLUSIONS

The quality of life of an individual suffering from severe motor impairments is importantly affected by its complete dependence upon the caregivers. An assistive device, even the most advanced, cannot substitute – at the state of the art – the assistance provided by a human. Nevertheless, it can contribute to relief the caregiver from a continuous presence in the room of the patient, since the latter can perform some simple activities on its own, and most importantly, because the attention of the caregiver can be recalled by some form of alarm.

This means that in a clinical environment, the cost of assistance can be reduced, since the same number of paramedics or assistants can care after a higher number of patients (in non emergency conditions). In a home environment, the life of relatives can be less hardly affected by the presence of the impaired individual.

Most importantly, the patient perceives that he/she is no more bound to rely on the caregiver for each and every action. On one side this increases the sense of independence of the patient, on the other side this grants a sense of privacy, which is almost absent in the case another human has to take care of the task. For both reasons, the quality of life of the patient is sensibly improved.

The usefulness of the BCI-based interface has been recently investigated in other studies [12]. The improvement of quality of life brought by such a interface is expected to be relevant only for those patients who are non able to perform any voluntarily controlled movement. The advances in the BCI field are expected

to increase the performance of this communication channel, thus making it effective for a broader population of individuals.

#### 6. ACKNOWLEDGMENTS

This work is partially supported by the Italian Telethon Foundation Grant GUP03562 to the institutions: Fondazione Santa Lucia, Dip. di Informatica e Sistemistica - Università La Sapienza, Telecom Italia Learning Services.

#### 7. REFERENCES

- [1] Wolpaw JR, Birbaumer N, McFarland DJ, Pfurtscheller G, and Vaughan T M, "Brain-computer interfaces for communication and control" Clin. Neurophysiol. 113, 767–791, March 2002.
- [2] Wolpaw JR, McFarland DJ, Neat GW, Forneris CA. "An EEG-based brain-computer interface for cursor control". *Electroenceph clin Neurophysiol*;78:252–259, 1991.
- [3] Wolpaw JR, Birbaumer N, Heetderks WJ, McFarland DJ, Peckham PH, Schalk G, Donchin E, Quatrano LA, Robinson LA and Vaughan TM "Brain-computer interface technology: a review of the first international meeting." *IEEE Trans Rehabil Eng*, 8:161–163, 2000a.
- [4] Birbaumer N, Elbert T, Caravan AGM and Roch B. "Slow potentials of the cerebral cortex and behavior." *Physiol Rev*, 70:1–41, 1990.
- [5] Schalk G, McFarland DJ, Hinterberger T, Birbaumer N, Wolpaw JR "BCI2000: A general- purpose brain-computer interface (BCI) system", *IEEE Trans Biomed Eng*, 51, 1034–43, 2004.
- [6] Pfurtscheller G and Neuper C "Motor imagery and direct brain-computer communication". *Proceedings of the IEEE*, 89: 1123–1134, 2001.
- [7] Millán J del R. "Adaptive brain interfaces". *Communications of the ACM*, 46:74–80, 2003.
- [8] Millan J, Franze M, Mourino J, Cincotti F, Babiloni F. "Relevant EEG features for the classification of spontaneous motor-related tasks". *Biol Cybern* 86: 89-95, 2002.
- [9] Oriolo G, Ulivi G and Vendittelli M. "Real-time map building and navigation for autonomous robots in unknown environments". *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 28, no. 3, pp. 316-333, 1998.
- [10] Oriolo G, De Luca A and Vendittelli M. "WMR control via dynamic feedback linearization: Design, implementation and experimental validation". *IEEE Transactions on Control Systems Technology*, vol. 10, no. 6, pp. 835-852, 2002.
- [11] Dragicevic P, and Fekete JD "Input Device Selection and Interaction Configuration with ICON", proceedings of IHM-HCI 2001, A. Blandford, J. Vanderdonck, and P. Gray, (Eds.): *People and Computers XV - Interaction without Frontiers*, Lille, France, Springer Verlag, pp. 543-448.
- [12] Kübler A, Nijboer F, Mellinger J, Vaughan TM, Pawelzik H, Schalk G, McFarland DJ, Birbaumer N, and Wolpaw JR, "Patients with ALS can use sensorimotor rhythms to operate a brain-computer interface", *Neurology*, vol 64 p1775 – 1777, May 2005.