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User experience to improve the usability of a vision-based interface

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ABSTRACT

When we develop an input device for users to communicate with computers, we have to take into account that end-users must consider the utilization of the device to be *effective, efficient* and *satisfactory*. Users whose expectations are unmet by the interface will tend to abandon it. In this paper we present a vision-based interface for motor-impaired users; a multidisciplinary group developed this interface. The user's preferences are a critical issue when selecting an access device; therefore, user requirements should be included in the design. Usability evaluation should be integrated into relevant phases of software development. In order to evaluate the design, we present a process with multiple user studies at different development stages. We describe the combination of a development project and its implementation, with user experience considerations embedded in the process. Finally, we studied the performance of the interface through several tests, paying special attention to satisfaction and fatigue. From our results we observed that although several users found the interface tiring, their satisfaction level was encouraging, suggesting the interface is usable.

1. Introduction

The purpose of this paper is to describe the design and development of a hands-free interface based on computer vision techniques. We observed and analysed how end-users work in order to improve the system's quality and usability.

Human–computer interaction (HCI) is the study of communication between humans and machines, and as the term suggests, the user is essential to this field. Unfortunately, systems developers frequently overemphasise the technology rather than the user (Norman, 1999). When we design systems for users to communicate with computers, we must consider the user first, as the goals for a good human–computer interaction are decreased errors, increased satisfaction for the user, and better performance of machine-assisted tasks.

User interface paradigms evolve continuously in order to benefit from technological advances. Recently, interfaces that use computer vision techniques (vision-based interfaces) have gained importance, as the visual channel can provide much information for HCI purposes. Among the applications of computer vision (Porta, 2002; Turk and Kölsch, 2005), we are interested in those applications for HCI. Vision-based interfaces can offer users with disabilities a better access device. As well, people with motion impairments often prefer camera-based communication interfaces, because these interfaces are customisable and comfortable (Betke, 2008).

We developed a hands-free interface based on computer vision technologies for motor-disabled users who cannot effectively use common input devices. It works as a pointing device (like a mouse) with a webcam, with nothing attached to the user and with normal background and lighting conditions. The interface transforms the user's nose motion into mouse pointer positions, and a graphical event toolbar handles mouse events. Early hands-free interfaces based on computer vision techniques were general systems with different applications; among them, mouse pointer control (Toyama, 1998; Bradski, 1998; Gorodnichy et al., 2004). However, designing a device for a particular user population presents a different set of problems than applying an existing system to a specific task. Moreover, we must be aware that a user may abandon an assistive technology device that is not useful or usable (Scherer and Galvin, 1996; Riemer-Reiss and Wacker, 2000; Rogers, 1995).

In parallel to our system, other researchers have developed similar vision-based interfaces (Perini et al., 2006; Palleja et al., 2009; Morris and Chauhan, 2006; Kjeldsen, 2006; Mauri et al., 2006). They have explained very little about their development process or about the influence of end-users and evaluators on interface design.

Similar to our development process is the case of the Camera Mouse. This system of Betke et al. (2002) was the first vision-based system designed and developed to be an access device for disabled users. In their works, they described the importance of collaboration of a multidisciplinary group (Gips et al., 2002) and the system's

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evolution together with user experiences (Cloud et al., 2002; Connor et al., 2009; Akram et al., 2006).

In order to evaluate our system's usability, we will define usability according to ISO 9241-11, the international standard on Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs); specifically, Part 11: "Guidance on usability". Usability in this standard is defined as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". The three measurements to control, according to ISO 9241-11 (ISO, 1998), are influenced by:

1. Users: who are the product's end-users? Are they experienced users? Do they have any disabilities?
2. User goals: what kind of tasks do users want to accomplish when using the product?
3. Use context: where is the product going to be used, and under which conditions?

Methods for planning, achieving, testing and evaluating usability and accessibility must exist throughout software or hardware design development and not only within user interface development (Seffah and Metzker, 2004). Based on ISO 9241-11, usability cannot be measured directly (Hornbaek, 2006). Experts mention the difficulty of usability measurement and the need for criteria to choose the most appropriate usability metrics (Hvannberg et al., 2007). The aim is to measure each of the usability parameters: effectiveness, efficiency and satisfaction (Hornbaek and Frokjaer, 2008). In order to evaluate them, we have to use procedures and techniques from usability engineering, such as interviews, satisfaction questionnaires, the identification of user profiles, and automated usability evaluation techniques (Dumas and Redish, 1999; Petrie et al., 2006; Stary and Eberle, 2008).

The main goal of the evaluations is to enhance product design to make the product more useful for the user and to make the user more comfortable. Evaluators of pointing devices frequently use Fitts's Law (ISO, 2000; MacKenzie, 1992) to assess the relationship between movement speed and accuracy (MacKenzie et al., 1991; Douglas et al., 1999; Isokoski et al., 2007). However, evaluators must pay special attention when working with children or disabled people and using Fitts's Law (Hourcade et al., 2004; Donker and Reitsma, 2007). Moreover, reviewing work on hands-free vision-based interfaces and their evaluation with disabled users, we could not find common tasks or techniques.

Therefore, when studying interaction between children or adults with special needs and new devices, the interplay among software developers, designers and evaluators is essential (Skov and Stage, 2008). Integrating usability evaluation into the product life-cycle will allow richer feedback in development, and it will engender a higher-quality and more satisfying product.

The work presented here is part of a project that began in 2006 and is still in progress. The technical basis and the first tests to evaluate the system with non-disabled users in order to analyse its accuracy and operability are detailed in previous work (Varona et al., 2008). In 2007, disabled users began working with this initial prototype. This prototype is described in Section 3. Two evaluations of the prototype were carried out: the first one in a centre with disabled users, and the second one in an external group with non-disabled users. The method to embed the system in the centre for disabled users and their first experiences are briefly explained in previous work (Manresa-Yee et al., 2008), as is the evaluation of the external group (Ponsa et al., 2009).

In this paper, we present the project's final stage, and describe our efforts to incorporate usability evaluation with end-users in the final development of our hands-free interface. Specifically, we describe a combination of development with user experience considerations in order to make the interface more usable, taking into account users' special needs. The therapists collaborating with us had worked with different assistive technologies and had experienced the difficulties of adapting systems to users, which had caused them to reject these technologies. Our aim was to develop our own system in order to be able to modify it and fulfil all our users' requirements.

The paper is organised as follows: Section 2 describes how we developed the hands-free interface and the initial requirements analysis. Section 3 describes the first prototype and its testing. Section 4 analyses the effect of users' usability recommendations and evaluators' feedback. In Section 5, we present some performance results from nine months of work in a cerebral palsy centre. Section 6 concludes our work.

2. SINA project: HCI for motor-impaired users

The main aim of the project was to design and develop a really useful and usable hands-free interface in order to achieve an input device for users with motor impairments. In the project it was very important the collaboration of professionals coming from different backgrounds and disciplines such as human factors, special education, technology for education, occupational therapy and computer science.

2.1. Motivation

People with various diseases or injuries may not have total control of their physical motor capabilities, causing restricted motion, poor body coordination, reduced strength, spasms or tremors. Users with any of these conditions may not be able to use traditional computer input devices effectively. However, many different human–computer interfaces are currently available: for example, switches, mice emulators or speech recognition systems. Such interfaces take into account the requirements of people with different capabilities.

Not all systems are suitable for everyone, so the selection of an input system is critical. The decision is influenced by issues such as the user's physical and sensory capabilities: for example, whether users count with a controlled and voluntary movement that they can perform repeatedly, their fine motor control or lack thereof, body parts' range of motion, strength, or fatigue. Cognitive capabilities will also be very important for users with attention limitations or memory loss (Shneiderman, 1998). Device properties are also taken into account, such as portability, adaptability to environment, and price. These characteristics help in choosing a system, but the user's personal considerations are critical. Therefore, even if a device is not the most suitable system for the user's conditions, if the user prefers it, it will be difficult to change this preference.

Scherer and Galvin (1996) estimated that 1000 assistive technology devices appear each year, but most of them are not tested, due to ignorance of their existence or due to their cost. Even when systems finally reach users, many are not accepted because of their lack of usefulness: "dissatisfaction typically results in discontinuance of the assistive technology product" (Riemer-Reiss and Wacker, 2000). According to Rogers' theory of diffusion (Rogers, 1995), there are two types of discontinuance: replacement (exchanging the system for another one) and disenchantment (rejecting the system due to dissatisfaction). One way of discouraging discontinuance and encouraging users to prefer a system is to involve users in the entire design process. The therapists participating in the project, who work daily with users who have cerebral palsy, agree that user involvement is important.

In the SINA project, the key to usability was to involve the users in early development stages. In the next section, we describe the life-cycle and the steps followed in the development of the hands-free interface.

2.2. Developing of the hands-free interface

We used a traditional software engineering process to develop the hands-free interface for motor-disabled users. In particular, we developed the system following a prototyping model to comply with Gould and Lewis (1985) principles when designing for usability: early focus on users and tasks, empirical and experimental studies with simulations or prototypes and iterative design.

Prototyping is especially good for designing good human–computer interfaces. "One of the most productive uses of rapid prototyping to date has been as a tool for iterative user requirements engineering and human–computer interface design" (Overmyer, 2002). Prototyping is cyclical and involves four steps: identifying requirements, prototyping, user review and revising and enhancing the prototype.

In the requirements analysis phase, a computer scientist with motor impairments helped us to identify the first requirement list. This user usually works with a trackball but has tested different interaction systems, among them hands-free interfaces. The user stated only a few initial requirements:

- *R1*: The system is non-invasive: the system works with no sensors, cables, stickers or any other element on the user. Users should feel comfortable.
- *R2*: The system is low-cost: the software should be free for the end-user and the overall system must be low-cost. Our system is free and works with a webcam.
- *R3*: The system works with the user's head movement: the system works by moving the head or the face. Our end-users are people whose upper limbs are not functional enough to work effectively with a mouse, but who have a minimum of head control. In our case, we transform nose motion into mouse pointer position on the screen.
- *R4*: The system works in normal environmental conditions: that is, with cluttered backgrounds and without special lighting conditions.
- *R5*: The system can execute all mouse events. A graphical event toolbar is always visible. Wait-and-click realises all events: that is, positioning the mouse pointer on the event button and staying on it for a particular number of frames to select an event. To execute the event, a similar action is needed.
- *R6*: The position of the webcam is flexible. As long as the user's face is within the image provided by the webcam, the webcam can be on the table, on the screen or over any other support.
- *R7*: The system is totally automatic. Users should rely as little as possible on others' assistance.
- *R8*: The system considers the user's head motion range and head control. Users have different ranges of head motion; therefore, the system moves with consideration of the head movements that the user can perform. Furthermore, the ability of every user to keep a steady position to execute, for example, a mouse event is different; the system should take this ability into account. We provide a configuration file for the user's personal settings. The settings in the configuration file are:
  - Click time: how long the user must remain on a position to carry out an event (in frames per second). This setting is required as some users find it difficult to keep steady due to spasms or tremors.
  - Range of click: the area around the active zone of the mouse pointer where events are effective (in pixels).
  - x jump and y jump: constants used in the mapping of the image point to the screen point. These parameters will allow users with small neck ranges to reach the screen's corners with little motion. Higher values will allow the user to reach the corners more easily but less precisely. The size and the position of the items that the user will work with should be taken into consideration.
- *R9*: The image shown in the processing window must be coherent with the user's motion. It should be a mirror image so as not to confuse the user.
- *R10*: Feedback must be in real time: users should observe that the mouse pointer position reacts in the same manner as their head motion.
- *R11*: The user must always be aware of the state of the interface. The event selected must be marked, and the system must show a message if any error occurs.

3. Initial prototype

Our first prototype fulfilled the requirements described in the previous section, and it was the first one that disabled users began using.

Our hands-free interface requires users to initially place their head facing the screen, avoiding any type of orientation: head panning, tilting, or rolling may cause the initial automatic face and facial feature detection to fail. Nevertheless, once the system is initialised, it works correctly for these head orientations (providing that facial features are visible).

The system is divided into two main modules: Initialisation and Processing (see Fig. 1). The Initialisation module is a totally automatic learning phase, responsible for extracting the user's distinctive facial features. It detects the user's face (see Fig. 2a) and the best features over the nose region to track (see Fig. 2b). The first approach was to involve the user in a calibration phase to analyse the relationships among the physical screen size, the image captured by the webcam and the user's head motion range. A first test with users who have multiple sclerosis made us change this idea, as the users found it complicated to understand. The Processing module tracks nose features and sends the position and event to the operating system so that it can place the mouse pointer and execute an event. If all features get lost, then the interface searches anew for the user's face and features.

Finally, the point used to map the position of the head onto the position of the mouse pointer is the mean of all the features used for the tracking. See Fig. 2c.

This paper does not describe the computer vision algorithms or more technical details of the hands-free interface; for more detail about these techniques, see our prior work (Varona et al., 2008).

This was the first prototype presented to users for evaluation. With every revision, feedback was analysed and if changes were justified, they were implemented and users started working with the new version immediately after its release. The system was continuously modified.

3.1. Testing

Three different reviews were done during the design and development of the system with disabled and non-disabled users. These tests were carried out by different professionals (technical, pedagogical, occupational therapists and human factors experts) involved with the direct implementation of the system, as well as outsider observers with technical and non-technical background.

The *first test* was done in laboratory conditions with non-disabled users. The intention of this evaluation was to prove that the system followed users correctly and that they could click with enough precision. This test demonstrated the system's functionality, especially its accuracy and operability. It was important to achieve an initial operating prototype. We wanted to present a

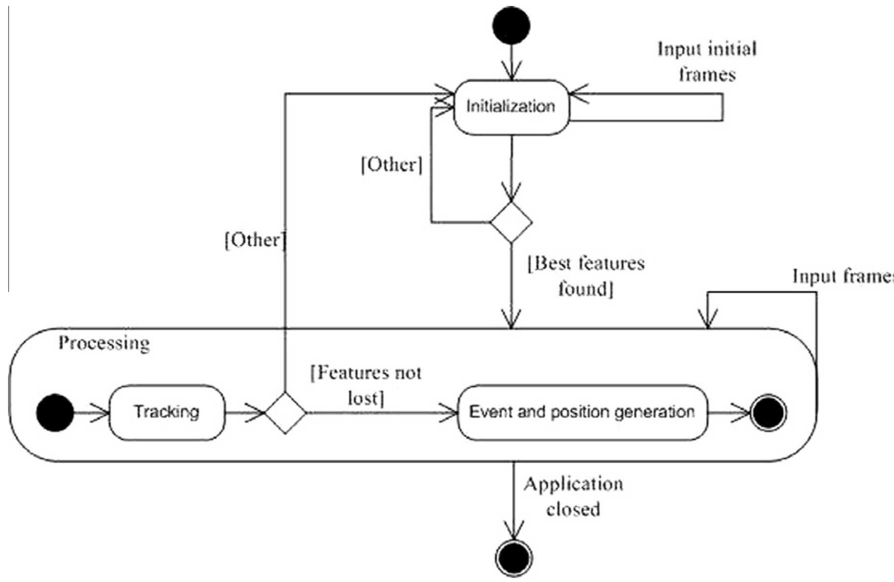

Fig. 1. UML-like diagram of the system (Varona et al., 2008).

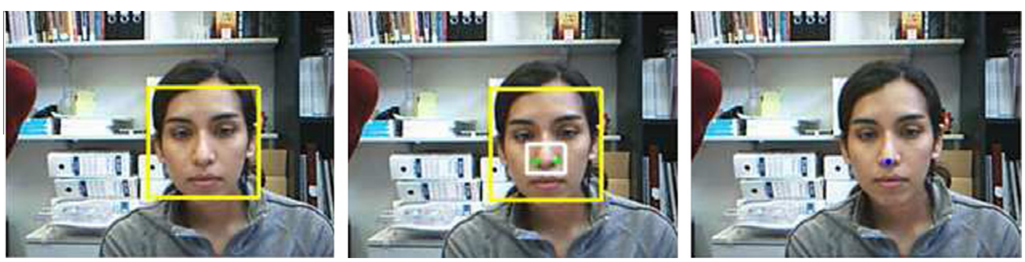

Fig. 2. Initialisation module: (a) Automatic face detection. (b) Best feature selection using symmetrical constraints. (c) Mean of all features: nose point.

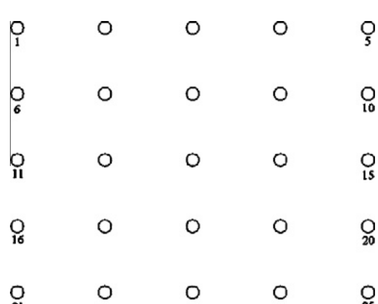

Fig. 3. The point grid pattern used for the interface's performance evaluation (the circle radius is 15 pixels).

prototype with a set of minimal conditions to the users who have cerebral palsy, as a non-working system could frustrate them.

The interface was tested by two sets of different users; one set had never experienced the application, whereas the other set was previously trained with the interface. We presented a grid of 25 targets arranged in five rows on the computer screen, and users were asked to click on every target. Each target had a radius of 15 pixels (see Fig. 3).

Users could follow the order they wished, and time was not limited. The user could make only one attempt at each target and if a click was executed, the closest target to the click was considered the objective and was coloured in order to notify the user that the target could not be clicked again. Distance data between the screen mouse pointer position and the closets target on the grid was stored when the user clicked outside the target to compute the distance for errors. Results were successful, with approximately 86% of clicks correct for new users and 97% correct for trained users. Moreover, the average error distance was small, five pixels for new users and two pixels for trained ones.

The measurement of Fitts's law applied in the measurement of throughput for ISO9241-9 (ISO, 2000) was evaluated once the design and development system phase was complete (Manresa-Yee, 2009). But in the initial system state, this accuracy test was sufficient for our purposes.

A *second test was* done by external evaluators from the Automatic Control Department of the Technical University of Catalonia with users with no motor disabilities and in laboratory conditions. This test was carried out by a group totally independent from the SINA project. They applied the GEDIS guide (Ponsa and Díaz, 2007) to validate the hands-free interface. The GEDIS guide is the 'Ergonomic Guide for Supervisory Control Interface Design', which covers all aspects of the interface design, such as interface calibration, the user-oriented graphical toolbar, head motion range and feedback in order to improve the effectiveness of human–computer interaction. They centred their study on the graphical event toolbar and a set of new recommendations to improve the user interface in ways such as location, visibility, size or colour use. This paper does not describe in detail the ergonomics of the hands-free interface, readers interested in more detail about these techniques are directed to prior work (Ponsa et al., 2009). Moreover, the non-disabled users tested the hands-free interface while working on pre-defined tasks with an interface of a domotic house (in laboratory conditions).

The external evaluation was important, as the interface was tested and observed by an independent group. Moreover, they could evaluate the quality of the system's documentation and the ease of installation and use.

The *third test* was done with users with cerebral palsy. Cerebral palsy (CP) is a term used to describe a group of chronic conditions affecting body movement and muscle coordination. Many of the users in the cerebral palsy centre were already working with some kind of assistive tool (see Fig. 4). These users were potential end-users of our interface, so it was ideal for us to evaluate it with them and to receive their feedback, although we have to consider the cognitive level of several users.

The centre's therapists chose the users with the following criteria in mind:

- The need for an alternative device to access the computer, prioritising users whose access system was not very effective.
- Users had to be able to continue their educational program with the computer.
- Previous experience with computers. Although the hands-free interface does not require previous experience, the therapists wanted the users to focus on the tasks and not on the use of a computer.
- Sufficient cognitive level to understand the interface and the instructions from the therapists.
- Physical conditions: head control and sight control.

Six persons, four children and two adults were selected to participate in the project. Users' ages ranged from 5 to 42 years and there were two women and four men. Sessions took place three times per week, 20 min for the children and 30 min for the adults. The data collected in this test were mostly based on observation of the users working. We wanted to introduce the interface without changing the tasks users normally performed when using the computer. All sessions were observed and controlled by a therapist, and an assistant monitored the users' evolution and filled in a spreadsheet. In the following sections, we will explain this spreadsheet in detail. Later these spreadsheets were analysed in order to extract results. Most of the enhancements made to the final system are due to feedback from these users and their therapists. They provided a lot of information, because they used the interface for long periods of time and their characteristics are totally different from those of the non-disabled users.

Users carried out their own tasks: that is, they continued working with their own educational activities, but they incorporated new tasks that they could not previously achieve due to their input device.

In Table 1, we describe the users and their previous access systems. We will explain one by one the observations made by the therapist of each user. We individually describe the case of each user, as they differ from each other greatly in capabilities and it is difficult to group them. We have to take into account continuous modifications to the system during its design and development. When studying each case, we have divided the evaluation into three periods: *initial*, *during* and *at the end*. The *at the end* period will be described in the Performance and results section. The *initial* evaluation was done with the laboratory's prototype; the *during* phase took place while modifying the prototype.

3.1.1. User 1

User 1, a 5-year-old boy, accessed the computer with switches before trying the hands-free interface. The goals proposed for him were to improve his head control and to increase his autonomy as well as his interaction with the environment. He was highly motivated and during his sessions with the interface, he could control the mouse's position and maintain his posture steadily to execute mouse events. The user kept his head completely straight during the sessions, but a physical deterioration made him abandon the sessions and therefore he was removed from the project; this means that spreadsheets were not filled out in his sessions.

3.1.2. User 2

User 2, a 12-year-old boy, accessed the computer with switches before trying the hands-free interface. He had tried different joysticks but with no acceptable results. The goals to achieve were to develop his spatial organisation, improve his accessibility and

Fig. 4. (a) Users using SINA. (b) Previous access devices.

Table 1
Motor impairment users' profile in the designing and development phase.

Id	G	Age	Diagnosis	Previous access method
U1	M	5	Child's CP spastic quadriplegia with left predominance	Switch scanning mouse
U2	M	12	Multi-handicapped case of CP. Child's CP, quadriplegia, spastic-athetoid with major affectation in inferior limbs by spasticity and in superior limbs by athetoid. He frequently suffers from breathing and digestive problems as well as epileptic seizures	Switch scanning mouse. He has tried different joysticks but with no acceptable results
U3	F	14	Glutaricaciduria I	Head pointer, joystick handled by the chin and mouse emulator
U4	F	42	Progressive spinocerebellar neurodegenerative disease	Numerical mouse or standard mouse
U5	M	30	Spastic quadriparetic cerebral palsy with bipolar affective disorder	Numerical keyboard with a keyguard and he typed using a pointer or a finger
U6	M	16	Muscular dystrophy of Duchenne with hyperactivity diagnosis	Standard keyboard and mouse

his interaction with the computer and dissociate his head movements. At first, he could not follow the instructions and his head motion was abrupt and uncoordinated. He could not control the mouse pointer and he needed verbal and physical assistance from the therapist for carrying out the movements. He could not concentrate and he constantly lost focus, thereby losing his nose's tracking point. For his training, very simple exercises in Microsoft Paint and PowerPoint were used. During the sessions, although he found it difficult to use the interface, his motivation was always high during the 20-min sessions.

3.1.3. User 3

User 3, a 14-year-old girl, used a head pointer to access the computer as she had total control of her head. While she was learning the hands-free interface, she also started working with a joystick handled with the chin, as her therapists wanted to try different devices to select the best one for her for the future. The goals were to improve her access and interaction with the computer, achieve more functional communication and correct her general working posture, as she found it very tiring to work with the head pointer. In her first sessions with the interface, she worked with her neck flexed and exerted a great amount of motor effort. She frequently lost the tracking point due to her involuntary movements or because she paid attention to other stimuli. The trajectory of the mouse pointer was discontinuous and uncoordinated and she could not maintain the mouse pointer steadily enough to carry out an event. During the sessions, she participated dynamically in task selection and she was trained with memory games and educational applications.

3.1.4. User 4

User 4, a 42-year-old woman, accessed the computer via the numerical keyboard emulating a mouse, and sometimes with the standard mouse, but with many difficulties. The goal to achieve was to improve her accessibility. Initially, she would become physically and psychologically tired. She could not move the cursor to a desired position because of her lack of head coordination. She could not keep her position steady, due to her tremors, and at first it was difficult to personalise her settings. During the sessions, she started to train orientation issues (motor awareness of directions) and to keep the mouse pointer steady in Microsoft Paint.

3.1.5. User 5

User 5, a 30-year-old man, accessed the computer with a numerical keyboard with a keyguard, and he typed using a hand pointer or his finger. The goals to achieve were improvement in his head control and better access to and interaction with the computer. In the first sessions, he tried to control the mouse position using his gaze, and the initial detection of his face was difficult due to his normal tilted head position. During the sessions, the tracking point frequently got lost due to his lack of head control, and he was almost removed from the project as it was not effective for him. But together with the centre's physiotherapist, his therapists decided to use the hands-free interface to reinforce his head control and motion by using Microsoft Paint and PowerPoint templates to exercise his neck.

3.1.6. User 6

User 6, a 16-year-old boy, was the 'control user' as he could interact with the computer with the standard mouse and keyboard. The goals for him were to experiment with alternative access devices, as it was necessary to introduce him to assistive technologies due to his probable future physical deterioration. In his first sessions, he showed very good control of mouse motion although it was difficult for him to remain steady enough to select an event from the toolbar. During the sessions, his training was done with car games and by searching images on the Internet to create Microsoft PowerPoint presentations.

With the first two tests, we demonstrated that users without disabilities could work with the system, but working with cerebral palsy users, we discovered new concerns. Improvements will be described in the following section.

4. Usability of the hands-free interface

In this section we will describe the new requirements that appeared once we started working with end-users. Based on feedback from the three tests, new requirements appeared and important recommendations were given in order to improve the prototype. These requirements were analysed and implemented if the effect on the system was significant. Some modifications were small and did not require a great programming effort, but improved the usability of the system.

As mentioned before, this project was carried out by experts from very different areas; therefore, the overall process enriched the know-how, the techniques and the methods used in these diverse disciplines. The mix of professionals contributed to improve the quality of the system and of development.

The experience of the technical group working with disabled users and in our case with users with cerebral palsy was null. The pedagogical group, experts in special education, provided the techniques to facilitate the approach to the cerebral palsy centre. Meetings among the technical staff, pedagogical staff, and the therapists of the centre were carried out to prepare to introduce the interface to the selected users. We planned with great care an agenda, a user profile registration form and a spreadsheet to register each session. This spreadsheet contained information about the physical state of the user that day (state, humour), technical setup (parameters for the hands-free interface, webcam settings, user settings), the tasks carried out and the difficulties that arose.

It was essential to work directly with the users' therapists, as they know their users (Potosnak et al., 1986) and know which tasks are more adequate to carry out with the users as all of them have different capabilities. Some only do action/reaction activities, while others can surf the Internet working with a graphical keyboard to write and others cannot even work with the event toolbar yet.

As we will present next, the system was modified not only in its graphical user interface, but also in its functionalities.

- *R12*: The system's event toolbar contains images instead of text, and they are as close as possible to the metaphor of a standard mouse. Images representing different mouse events must be meaningful and the user should relate them directly to the mouse's events. The graphical interface has undergone many changes since the first prototype in order to present a more natural mapping (Constantine and Lockwood, 1999). The earliest version was entirely text-based (see Fig. 5a), and then the text labels on the buttons were replaced by images in order to create a metaphor for the mouse (see Fig. 5b). Finally, the hands-free system offers a more aesthetic interface created by a designer (see Fig. 6).
- *R13*: The system presents a correct combination of colours. The colours of the interface should follow eye characteristics and ergonomic and psychological constraints. This recommendation provided by the external evaluators still has yet to be applied. The opposite colours theory implies that certain colour combinations must not be used, in order to avoid post-effects. These post-effects can affect how the user stares at a colour: for example, when looking at red colour during certain time, this colour exhausts, inhibits and green appears. One of these combinations to avoid is blue and yellow.
- *R14*: The system's event toolbar adopts different initial positions in order to gain flexibility and adapt itself to the user. The initial position of the event toolbar was always on the right side of the screen, as normally, icons or menus are located starting on the left side of the screen for users who read from left to right. External evaluators recommended the option to place the event toolbar in three different positions: the right, up and down regions.
- *R15*: The system's initial window should disappear as soon as the system has located the user's face and features and the user's head motion has mouse pointer control. If the features followed get lost, such as when users turn their heads to talk to their therapists, the window system will automatically appear on screen and the system will initialise itself. The initial program window where a user can see their image and the cross on their nose (meaning that the system was tracking correctly) remained on the screen until the user hid it. This fact distracted the cerebral palsy users' attention as they kept staring at their own images. This change did not require a great effort for the developers, but it significantly improved the usability of the interface.

Fig. 6. Current user interface.

- *R16*: The system must respond with visual feedback to the user's action. As all the interaction is carried out by vision techniques with no physical contact with any device (Gorodnichy, 2006), visual feedback is offered at all moments in the events' toolbar to communicate with the user. The problem was that tracking feedback was lost when we hid the initial window. It is important to know if the tracking point is displaced or lost. Automatically, if all features being tracked (remember that several features around the nose are tracked and the mean of all these points is then mapped to the system) get lost, then the initial window will appear on screen. However, if features get displaced due to a fast movement like a spasm or an exaggerated change of light conditions, the user should be aware of the displacement. In order to receive feedback from the hands-free system, we rely on showing a window with the computer vision state in the event toolbar. The cross on the nose is expanded and occupies the entire image to make it easy to visualise tracking.
- *R17*: The file configuration was extended to add different parameters for the user to configure.
  - Position of the event keyboard: northern, southern or eastern portion of the screen.
  - Initial mouse's event: event selected for when the interface is initialised. Several users with cerebral palsy who just carried out action/reaction tasks had to have already selected an initial mouse event, as they still could not work with the event toolbar. Moreover, before beginning to work with the system, a profile window appeared in order to select and load the user's configuration file.

Fig. 5. Interface (a) event toolbar with text and (b) event toolbar with images.

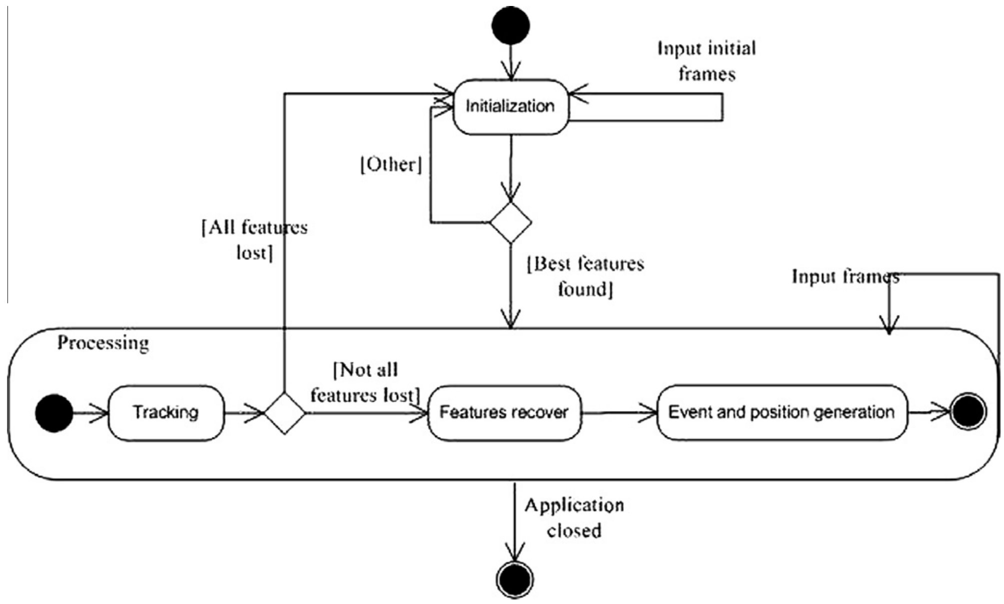

Fig. 7. New UML-like diagram of the system. It includes a new module for recovering features (Guasp et al., 2008).

- *R18*: The profile selection window will only appear if configured. If only a user uses SINA on a computer, then this window does not need to appear. In the cerebral palsy centre, only two computers were used, so a selection of the profile was made. When working in a house, there will probably be only one user needing this input device, and therefore the interface will automatically read their profile. This automation will make users more independent and will free them from the need for assistance, apart from someone switching on the computer, as the interface will execute when the operating system boots.
- *R19*: The system should always track the features around the nose region. If features get displaced, whenever the user looks straight into the webcam, we will readjust the tracking features to centre them in the nose region. While observing the users working for 20 or 30 min in each session, we observed that they had spasms, fast head movements, or distractions; several users' head was tilted to one side as it was their normal head position or because they got tired and could not hold their head straight. This caused the mean point of all the tracked features to displace and move out of the nose region: that is, features did not get lost, but just displaced, and therefore the tracking continued processing but moving the mouse pointer was not so easy. We had to add to the Processing phase a step to recover and update the features used to track (see Fig. 7). Every time the user's face looks up towards the webcam, we search for good features to track again on the nose region and update the set of features we are tracking, adding just a percentage of found features. Users do not participate actively in this phase, unless their normal head positions are tilted; then they will notice that the cross is not on their noses and they will have to straighten up their heads. Finally, users will just feel a subtle readjustment of the red cross on their noses. This process demands a high resource cost, but it improves greatly the operation of the hands-free interface for users with cerebral palsy.

5. User performance and results

Most of the modifications made to the system's design are the result of the therapists' and evaluators' observations. The data gathered are mostly qualitative, but quantitative results were also collected. In this section we describe the results and performance observed by the therapists.

5.1. Therapists' observations

At the end of the design and development phase of the SINA project:

- User 1 was still using the system as an access tool, although he was not included in the research project and his tasks with the computer were action–reaction applications. The therapists' opinion was that this interface could be used for him for reinforcement tasks and for working on his head control.
- User 2 could move the mouse pointer to the desired position, and although sometimes he used the trial and error technique, he always reached the target. He could move his head slowly and smoothly and his motion was more coordinated and constant. Moreover, he could focus and concentrate on the tasks, and he was working with more complicated applications. The interface allowed the user to explore orientation directly and he was starting to work autonomously with simple programs.
- User 3's results were very successful, as at the end of the evaluation, she controlled her head totally and her posture was better and not as stressed as before or when using the joystick. She was more relaxed and she hardly presented involuntary movements while she was working with the interface. She could move the mouse pointer in a controlled way and could follow trajectories as well as keeping the mouse pointer steady in a position in order to carry out an event. Moreover, she was starting to use the graphical keyboard for writing. The therapists and the user stated that this interface offered her a faster method to access the computer and that up to that moment it had been the best device for her.
- User 4 was working on cognitive issues with educational applications and she could work with the interface in a more relaxed and successful way. She did not get tired, and she was starting to use the system in the computer room with no need for a therapist.
- User 5 was working on cognitive issues with educational applications using the click event; however, he could not yet click on the graphical event toolbar. The interface allowed him to train his head control and to interact in a more functional way than other devices.
- User 6 could use the system independently; he used all the events in the graphical event toolbar and he could write with

the virtual keyboard. Moreover, the interface improved his body posture when working with the computer.

The therapists' conclusion is that all users improved in some way their access to the computer with the hands-free interface. This improvement is related to the experience of the users with the system and the system's usability enhancement. Most of the interfaces require a training period, but in this case, training would have not been enough. For example, several users could not use the system properly due to their involuntary movements, and the initialisation phase was continuously restarting (R19 solved this). Others did not understand the different events of the mouse, so they needed a starting event. Without the user profile configuration, each user needed to set their parameters first in order to work properly with the system (R17 solved this).

At the end of the design and development process, users could carry out successfully the tasks presented by the therapists and they understood how the hands-free interface worked. Moreover, working with the hands-free interface allowed a better body posture for most users. They did not have to bend their backs or adopt poor body postures.

The therapists remark on different problems and difficulties from their previous systems. First of all, when the device allows contact, the user can displace it. Joysticks and keyguards (together with head wands) have to be very well secured on the table or onto the user because users present involuntary movements that can displace the devices. For example, when User 3 starts working with the head wand and the keyguard, the devices are well-placed; a problem can occur if she moves the keyboard or keyguard with the head wand or if the head wand band moves a little bit. After that, reaching some keys may be very difficult. Moreover, users using the joystick cannot make smooth nor continuous movements with their hands and arms, and therefore they have to reposition their hands every now and then. In addition, the other hand interferes with the movement of the hand controlling the device.

Scanning systems working with switches are a very slow access device, and systems such as head wands are very invasive for the user.

Several users work with better body posture or control their involuntary movements more when using SINA than when using other devices: for example, User 5 adopts a very uncomfortable posture when working with the joystick that causes him fatigue, as his neck is totally bent to look down. He continuously looks down at the joystick and looks up at the screen. When User 2 works with SINA, he controls his involuntary face and mouth movements because he concentrates more on keeping the mouse position steady, but with the joystick this is not necessary, so he continuously moves his mouth.

5.2. Effectiveness, efficiency and satisfaction evaluation

Before commenting on the results, we summarise the three concepts we are evaluating (ISO, 1998):

- Effectiveness refers to task performance; how accurately and completely did the user achieve the goals?
- Efficiency is the amount of effort that is required to achieve the level of effectiveness when achieving the goals. Efficiency is the relationship between effectiveness level and resource consumption.
- Satisfaction refers to how comfortable the user feels while using the system.

As we commented before, at the end of the first phase of the project, all users could complete their tasks. However, the mood and the fatigue of the user on a particular day could decrease the effectiveness of SINA (or any other device). We have controlled for the user's fatigue and the timing needed to carry out different tasks when measuring resource usage. Finally, we asked the therapist and the user about satisfaction through the session spreadsheet.

We controlled performance by measuring effectiveness, efficiency and satisfaction. Along with the experimental sessions, the spreadsheet presented was filled out and then analysed. Besides working with the user's educational program with the hands-free interface, tests with the users carrying out the same tasks with the previous access device were also observed in order to compare them. Comparisons among devices to control effectiveness and efficiency (time) measurements were carried out. Each user performed a different task and duration was measured. We will explain several tasks as examples of activities users normally perform with the computer.

The tasks' duration depends on the motivation, mood or physical and behavioural state of the user on a particular day. Therefore the therapist will be responsible for deciding whether a task has to be interrupted. What we consider more important when working with users who have cerebral palsy are the effectiveness and satisfaction measurements: that is, whether users could successfully finish the task and whether they feel comfortable with the interface.

User 2's task was to visualise a presentation given with Microsoft PowerPoint. To change the slide, he had to click over an image of 7.5 cm high and 10 cm wide and it was never put in the same area of the screen. The user needed 3 min and 14 s with SINA, and with the switch scanning mouse (with two switches), he did it in 2 min and 26 s. Scanning systems together with switches cannot be compared, as they are not pointing devices and moreover, require the assistance of someone to scan the screen. But what is important is to demonstrate that the user can successfully carry out the task with SINA.

User 3 had to write her name, ''MARIA'', with and without the virtual keyboard. The keyboard was 28 cm wide and 15 cm high and each letter was 2.5×2.5 cm. She did the test with the hands-free interface, a joystick held with the chin controlling the click with a button, the same device without controlling the click (that is, using a wait-and-click method) and finally using a head wand together with the physical keyboard plus a keyguard. The best time was with this last device in 10 s; the hands-free interface needed 43 s, and the task with the joystick controlling the click was done in 2 min and 49 s and without controlling the click she was not able to finish successfully as she wrote ''ASSFHMZAAARIA''.

Another task for User 3 was a web game, where the user had to position the cursor over several insects in order to move them over a path. The paths were zig-zags and there were five insects. The duration to finish successfully with SINA was 3 min and 8 s and with the joystick handled with the chin, she needed 6 min and 40 s. For User 3, SINA was so far the best input device for her, and it is still the access system she uses to interact with the computer at school and at home.

User 4's activity was to relate images with words in English. She tried the activity with 12 cards, 8.5×6 cm and with 18 cards 4×8 cm. In this case, she worked with the hands-free interface and with the standard mouse. She obtained better results with the standard mouse, 3 min and 29 s for 12 cards versus 5 min and 45 s with SINA. For 18 cards, she needed 6 min and 12 s with the standard mouse compared to 9 min and 52 s with our system. Again, effectiveness was correct for both systems. The standard mouse efficiency is better for this user, although the therapists say that this user in particular works with a better posture when using the hands-free interface than when using the standard mouse.

The task for User 5 was to play a game of Memory for educational purposes. There were 16 cards in 8 pairs, and the user had

Table 2
Quantitative results for comparison tests with different devices.

Id	Tasks	SINA	Previous system
U2	PowerPoint	3 min 14 s	Switch scanning mouse (two switches): 2 min 26 s
U3	Insects	3 min 08 s	Joystick handled with the chin: 6 min 40 s
	Writing	43 s	Joystick handled with the chin + virtual keyboard: (a) Without controlling the click: 1 min 49 s. She wrote ASSFHMZAAARIA (b) Controlling the click: 2 min 49 sWith the head pointer and real keyboard + keyguard: 10 s
U4	12 cards	5 min 45 s	Standard mouse: 3 min 29 s
	18 cards	9 min 52 s	Standard mouse: 6 min 12 s
U5	Memory	4 min 40 s	With numerical keyboard: after making 1 pair of 8: 6 min 09 s Afterwards, he was tired so the task was abandoned
U6	Search image	1 min 14 s	Standard mouse and keyboard: 16 s

Table 3
Fatigue and satisfaction levels after 20 sessions. They are classified into 1: low, 2: medium and 3: high.

Id	Fatigue	Mean 20 sessions	Satisfaction	Mean 20 sessions
U1	[a]			
U2	Variable. Fluctuates between Low and High	1.71	High	2.92
U3	Low	1.13	High	2.86
U4	Medium at first, but then stabilises at Low	1.35	Medium-High	2.32
U5	Variable. Fluctuates between Low and High	2.26	Medium	1.94
U6	In some sessions High but generally Low	1.56	High	3

[a] U1 uses the interface but he is not controlled by the spreadsheets.

to discover where the pairs were. Every card was 6 × 6 cm. In this scenario, SINA was more efficient than the numerical keyboard. With the numerical keyboard acting as a pointing device, after matching one pair out of eight in 6 min and 9 s, he was exhausted and he abandoned the task. But with SINA, he could finish the task successfully in 4 min and 40 s.

User 6's activity was to click over the Internet Explorer icon, write Google's URL (www.google.com) in the address bar, write COCHES ('cars' in Spanish) in the search text box, and click on the Search button. This user was the 'control user', as at that time he could use the standard mouse and the keyboard efficiently and effectively. He could totally control his head and therefore, although more slowly than with the combination of the standard devices, he could also finish the task with SINA and a virtual keyboard. Obviously, he was very fast with the standard input devices, as he needed only 16 s to carry out the complete task. With SINA, he used 1 min and 14 s.

Table 2 summarises the timings for the tasks using different access devices.

We can conclude that when tasks involve writing, all users who could use the standard keyboard were faster with it than with any other device using the virtual keyboard (with no prediction). The hands-free interface requires (in a default configuration) approximately 1 s to execute any event. Scanning systems together with switches are not comparable, as they are not a pointing device, and moreover, they require the assistance of someone to scan the screen. Therefore, although they may be more comfortable, they do not grant the user a complete interaction with the computer. Also, all users could finish the task with SINA, and continuous practice would allow users to complete the activity more quickly.

Our users' characteristics, such as their cognitive levels, low head-eye-coordination or lack of spatial orientation will not allow us to present to them the ISO 9241-9 multi-directional tapping test that uses Fitts's Law.

We analysed the first twenty spreadsheets that were filled in during each session. The sessions were carried out during 6 months, and were 20 min long for the children and 30 min long for the adults. Each user performed between 20 and 26 sessions. We paid special attention to satisfaction and fatigue information.

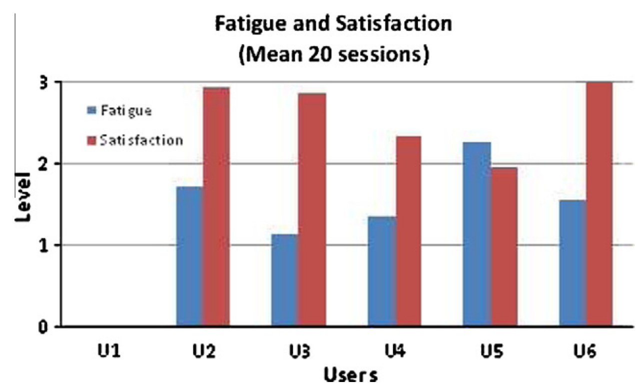

Fig. 8. Fatigue and satisfaction for 20 sessions. 3 is the maximum, 0 is the minimum.

Therapists observed that the user's mental and physical state on a particular day affected task performance strongly. Therefore, studying fatigue and satisfaction is very important. Fatigue and satisfaction levels were classified into 1: low, 2: medium and 3: high, see Table 3 and Fig. 8.

From these data, we can observe a positive result: although for several users the system is tiring, the satisfaction level is encouraging. The therapists' experience is that most of the pointing devices to access the computer demand physical (and sometimes mental) effort from the user, and therefore users get tired.

Moreover, an unexpected result was the rehabilitation of the user's head control. Users who had difficulties keeping their head straight or moving their heads reinforced their neck musculature and improved their head control. In fact some users are currently using SINA as a rehabilitation tool rather than as an access device.

6. Conclusion

In this paper, we wanted to show how users affected the usability of a product design. We presented the development of a hands-free interface based on computer vision techniques for motor-disabled users. We observed users working with our system over a long period of time and collected data in order to improve and integrate the user's needs and requirements quickly. We have designed and developed a usable system that is effective, efficient and satisfying for our end-users or for similar profiles.

In order for the project to succeed, a multidisciplinary group collaborated on all portions of the project. A mix of techniques, know-how and methods from all the areas were applied to the design and development of SINA. Moreover, we focused on users with cerebral palsy, so we needed the assistance of the professionals who work directly with these users. Working with users who have cerebral palsy was not easy at all, as all of them had their own characteristics. Therefore, we stress the importance of focusing early on the users, of multiple evaluations throughout the development process and of using a prototyping system in order to incorporate improvements and modifications as they appear.

As seen in the improvements, usability influence goes beyond the graphical interface. Usability affects the development process and the core of the system; therefore, it must be evaluated early. So, besides developing a more usable product, we lower the cost of changes.

Most research papers on vision-based interfaces present the final product together with (or without) an evaluation, sometimes even without the real disabled users of the system. None of them, except for the paper on the Camera Mouse system, described the process of improvements made to the interface due to the user's feedback; therefore, we recommend some principles for implementing similar vision-based interfaces for disabled users.

After we finished designing and developing the system, we extended the use of the hands-free interface to six more centres. The project is still under development, but the new goals are generalisation to computer rooms and ordinary schools with users with motor impairments and the study of rehabilitation and user posture. The more autonomous users are using it at home. We have been working with the new centres and evaluating their operation for 12 months.

The final release of the interface is available under a freeware license at the Web page http://sina.uib.es. This will allow us to have users around the world test the application and we will be able to improve the results by analysing their reports. The positive results obtained from our experience with the system have been awarded the Acces-IT 2009 Good Practice Label (http://www.access-it-events.org/).

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