Mapping Input Technology to Ability

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INTRODUCTION

As Europe becomes greyer and thus more reliant on health support, smart healthcare applications will play an increasingly important role in day-to-day life. These technologies will both deliver significant improvements in health care and simultaneously have higher requirements of user interactivity. This will involve both careful and attentive presentations of information and appropriate and efficient affordances for user input. Key to the use of these technologies is the ability of the end-users to communicate their needs, wants and internal states both to the support systems and with the technology itself.

From this perspective we can assert accessibility as a parameter in health care system design. In a larger context, more than just interacting with health care systems and providers is the issue of accessibility in an increasingly 'wired' world. So accessibility to computers implies providing support for disabled to communicate needs and internal states to supporting aids – both via persons and directly with environments. In this case environments could mean both health support systems and Quality of Living (QOL) environmental controls. Looking to the near future, smart healthcare will need to be situated in the context of independent living in environments of ambient intelligence (AmI) (Aarts, 2002), and although AmI research incorporates many novel forms of interaction ranging from gesture to speech recognition, there will continue to be a need for end users to also use more traditional forms of interaction in the forms of screens, keyboards and pointing devices.

A rough mapping can be made between computer input and motoric ability and output and sensory ability. Because of this basic division it can become too easy to focus on one or the other set of adaptations to solve accessibility problems of specific persons. Unfortunately, and especially often in persons with developmental disabilities and those experiencing the decline of abilities that accompanies aging, sensory and motoric disabilities often manifest in comorebidity[1]. Because of this, the range of needs and abilities is very large, thus an end user in need of accommodation becomes a universe of one (Erikson, 1958) such that no 'standard' solution exists on the shelf. This makes the choosing and integration of AT into an individuals life an especially

[1] **Comorbidity** - A concomitant but unrelated pathological or disease process.

difficult task to do properly. Therefore implicit in the discussion of accessibility is the AT professional as a critical stakeholder(Marcia J. Scherer & (Editor), 1996).

In this chapter we will discus input adaptation based on motoric dysfunctions First, we will initially present the problem that the design is based upon. The attributes of the potential end users and discussions with motoricly afflicted persons take the design space from dry technical specifications to a more informed and nuanced understanding of the problem space. Next we present a discussion of current literature and the state of the art in commercial offerings. Following this is a presentation of the process of the design of the novel input system, ***Etsedi*** and the different applications for this design. Finally we present the system itself, first as a high level description of the system, then as individual components and finally its integration into the operating system and use. Following this is a brief description of evaluation by users and a discussion of work to follow.

THE DESIGN PROBLEM

Most accessibility system designs for people with different disabilities focus on how to give the information to the user. For example, considering the size of the letters or the voice to read the information for the people with visual impairments. But, how can a user manage this information if she cannot access the inputs of the system? People with motor impairments, especially those with disabilities in the hands and arms often cannot access the devices because they do not have enough control to use keyboards, mice and other external controls. Thus what follows is a study of computer input accessibility problems and the development of an alterative system.

The Target Population

People suffering from what we have categorized as motoric disabilities demonstrate a wide range of different kinds of problems in using devices which require precise control. In the case of paralysis, those afflicted cannot move some parts of their body, and may require the use of augmentative devices to control new technologies using eyes, head, or mouth in the place of hand movements. Some neuron diseases cause loss of strength in the muscles, so people afflicted may have problems initiating movement in their limbs and often cannot hold things or press controls or buttons. One of the functional problems of some diseases is spasticity, a problem involving relaxing specific muscles and causes movements which cannot be controlled. A person with spasticity often cannot be precise with his movements and cannot reliably hold things because they often drop them

There are different reasons because people could have mobility problems. Spinal cord injury can occur from many causes: trauma (e.g. automobile crashes, falls, diving accidents), tumour, ischemia, developmental disorders (e.g. spina bifida, meningomyolcoele), neurodegenerative diseases, and others. As a result of serious injury of the spinal cord, they can lose the mobility of upper and lower limbs. Thus they do not have the ability to move any part of the body but their head and, to some degree, their neck. So, in this case the user is limited to using eyes, voice or head for all interactions.

Other common diseases are different neurological disorders. These kind of disorders can affect the central nervous system (brain and spinal cord), the peripheral nervous system, or the autonomic nervous system. Multiple sclerosis and cerebral palsy are well known, occur with relative frequency, and have severe motor consequences. Motor neuron diseases are progressive degenerative diseases causing paralysis along the body. Persons suffering from them typically lose mobility and control of upper and lower limbs, and with the time lose the control of neck and head as well. Other diseases can affect the patient psicomotricity, which usually manifests in two ways, as dysarthria and as motor control problems.

Multiple sclerosis (MS) is primarily an inflammatory disorder of the brain and spinal cord in which focal lymphocytic infiltration leads to damage of myelin and axons. Myelin supports of the transmission of nerve impulse between brain and other parts of the body. When myelin is missing the messages between the brain and the body cannot be transmitted correctly. This affects movement coordination and perception of the sensations of the body. Most multiple sclerosis patients can control their body functionalities, but when this degenerative disease is advanced they lose motor control both in power and in fine grained movement(Portillo, 2008).

Some of the motor neuron diseases are:

- Amyotrophic lateral sclerosis (ALS, also called Lou Gehrig disease)
- Lateral sclerosis
- Spinal muscular atrophy
- Progressive bulbar palsy

ALS it is a progressive neurological disease with degeneration of lower motor neurons. The first symptom is muscle weakness, especially in the arms and legs. As the disease progresses the patient has difficulty swallowing) and talking, and later breathing difficulties as the disease affects the accessory muscles of respiration. Eventually muscles atrophy and the patient becomes functionally quadriplegic. Mental processes are not affected, so that the patient remains alert and aware.

Multiple Sclerosis (MS) or Amyotrophic lateral sclerosis (ALS), are progressive degenerative diseases which cause paralysis along the body. These patients progressively loose communication and mobility ability and new technologies can be very helpful for them. But if they have severe mobility problems they cannot access communication systems. They typically lose mobility and control of upper and lower limbs, and with the time lose the control of neck and head as well.

Cerebral palsy (National Center on Birth Defects and Developmental Disabilities, 2002) refers to a group of disorders that affects a person's ability to move and to maintain balance and posture. It is due to a nonprogressive brain abnormality, which means that it typically does not get worse over time, though symptoms can change over a person's lifetime.

One of the functional problems of the cerebral palsy disease is spasticity (75% of the people with this disease are affected). This is a problem relaxing specific muscles and causes movements which cannot be controlled. A person with spasticity cannot be precise with his movements and cannot reliably hold things because they often drop them. Other important problem they sometimes have is dysarthria. Dysarthria is a speech disorder characterized by poor articulation. People suffering from cerebral palsy often have problems meeting new people which causes social exclusion. Alternative and augmentative communication can be very useful, but some communicators cannot be accessed by these patients due to their motor control problems.

Consequences of stroke are paralysis, cognitive problems, aphasia, emotional problems, problems in every day activities and pain. Paralysis of one side of the body is very common in patients with stroke. This paralysis is called hemiplegia. Another common disability is the motoric dysfunction of one side of the body or hemiparesis. This kind of paralysis can affect only the face, one arm or one leg, or all of one side of the body and the face at the same time. Motor impairments can affect the balance or coordination of the patient also (National Institute of

Neurological Disorders and Stroke, 2000).These patients usually have to retrain their body to recover the mobility and often do not recover it. Another consequence is difficulty in verbal communication. These can manifest as problems in understanding (called aphasia) or in talking or building phrases (dysarthria).

Other causes of motoric disability include arthritis, epicondylitis and tendonitis which manifest as pain in different muscles or tendons which occur the elderly or people who are very athletically active. Sometimes taking drugs can ameliorate this, but often the patients still cannot reliably hold things or are prevented from making critical movements because of lost hand skills.

People suffering from what we have categorized as motoric disabilities demonstrate a wide range of different kinds of problems in using devices which require precise control. In the case of paralysis, those afflicted cannot move some parts of their body, and may require the use of augmentative devices to control new technologies using eyes, head, or mouth in the place of hand movements. Some neuron diseases cause lost of strength in the muscles, so the people affected of muscular dystrophy, multiple sclerosis or ALS have problems initiating movement in their limbs and they often cannot hold things or press controls or buttons.

Current Alternative Approaches for Computer Input

As discussed above, people with motor diseases may have difficulty pressing buttons, holding objects or controlling hand movements, especially when precision is needed. Because each disease has different consequences in each person, individual solutions are required (M. J. Scherer, 1996). Although many solutions can currently be found in the market, for some there is no appropriate technology available.

An early approach to provide accessible input was to use voice for input requirements. A lot of voice recognizers were designed to control the systems using special words as commands. But this kind of systems had two problems:

1) Those with dysarthria problems cannot pronounce words properly and as a result their words could not be recognized.
2) The systems requirement for uniform pronunciation of the commands placed too high a workload on the user because she had to force her voice to accommodate the system in the same way each time.

Computing environments that use the WIMP[2] interaction style to provide a user interface require a way to allow users to navigate the screen. To do this mice are very useful because the user can move about in the screen quickly and precisely. But people who have problems in controlling the movements of their hands and arms find mice very difficult to use because they are based on precise and controlled movements to select the areas on the screen the user is interested in. Mice, or devices functioning as mice, currently come in a wide variety of forms

Figure 1 Keyboard Adaptation Overlays

[2] **WIMP** stands for "window, icon, menu, pointing device", denoting a style of interaction using these elements.

such as trackballs, wireless mice, joysticks, and head mice which may solve accessibility issues for some users.

Adaptations that solve the screen-positioning problem for some with motoric disabilities include using trackballs or joysticks built for computer games. Another approach is special mice designed for people with motor impairments which are heavier than the normal ones and resist being moved with spasmodic motor actions (Trewin, 1996). Another possible solution is to use a keyboard to control the pointer of the mouse, for example using the arrows from the numeric keypad. This possibility can be configured using the accessibility options from Microsoft Windows or Apple's operating systems.

People lacking mobility in hands or arms often can use their heads or eyes to control the pointer of the mouse. There are a number of 'head mice' on the market (Smart Nav, for example) which are typically controlled by the movements of the head. To use these types of head mice control of the neck is critical and therefore a user has to have fine-grained control of the movements of the head. This type of exertion can be very painful over long-term use and not all the people with paralysis have such accurate control of their neck (Bentz, 1998). For those who cannot use mice or 'head mice' another approach is controlling the movement of the pointer using their eyes. An example of this system is the Iriscom system which is based on eye tracking. Some people in bed who cannot move any part of their body can use this system to control the computers or their environment using domotic systems.

The above solutions work with the positioning problem, however mice also have a clicking or selection function. If the user has motor problems sometimes cannot press the buttons of the devices to perform a 'click', and 'double click' usually is very difficult because it typically must be done in a quite short time span. People who can move any part of their body can use pushers of different kinds to communicate a selection event with hands, feet, head, or chin. An alternate approach is to communicate selection using sip and puff technology or tongue switches. However for each event (click, double click, click with button on right, selection) a separate input is needed, resulting in too many different tools to be used effectively. To solve this tool explosion problem, developers provided a modification of the system software (or as an additional application) that produces a click event when the pointer is stopped on the object for a short (user selectable) time. Using this software the user can initially select the functionality he wants to activate and next indicate the screen item that he desired to affect. In some cases to do this the system provides a menu with one button for each event on the screen.

The other typical input modality in WIMP systems besides pointer movement and item selection is character input. This is typically done with a keyboard. This is very useful to input text for people without motor impairments. However for those who cannot sufficiently control movements of their hands and arms can have difficulty inputting text with a keyboard. For this reason some special keyboards and accessories have been designed. Those designs are very useful to input text for people without motor impairments. However for those who cannot sufficiently control movements of their hands and arms can have difficulty inputting text with a keyboard. For this reason some special keyboards and accessories have been designed.

People with motoric problems in hands and arms can sometimes be unable to press the keys of the keyboards because they do not have enough precision. For those who do have enough force to press keys, but have motoric problems, keyboards with bigger keys or special covers with holes for each key can be placed over a standard keyboard (Trewin, 2002). These covers are very useful in preventing the pressing of unwanted keys. In the case of people with motor problems who do not have enough strength to press keys, keyboards with less push resistance can be provided.

Beyond keyboard additions, keyboards which can be changed depending on the needs of the user have been implemented (Trewin, 2002). An example of this type of keyboard is Intellikeys, which is basically a large matrix of very sensitive sensors. The sensors can be grouped or divided into different sections by software configuration, allowing personalizing the buttons' size, distribution or functions.

But for the people who cannot use their hands to type on the keyboard a head pointer device can be used(Marcia J. Scherer & (Editor), 1996). This device consists of a bar, which is affixed onto the head. To use the device fine motor control of the head and neck is needed for the user to press the buttons using the bar by moving down and up the neck and head.

Figure 2 - Virtual Keyboard

Virtual keyboards (Figure 2) are another useful replacement for physical keyboards for people with motoric disabilities because they can be used with different screen positioning and selecting input devices as were discussed above. Additionally they may be used with software application techniques like scanning[3] which can be used along with various alternative screen positioning and selecting technology.

But keyboards can be used for more input functions than simply character entry. Computer keyboards offer other kind of actions using shortcuts like CTRL+c (copy function), CTRL+v (paste function), CTRL+ALT+Supr (to show administrator options) Those shortcuts are very useful for some actions because less activity from the user is required by turning scripts into single commands. This is very useful for the people with motor impairments because they need more time to control their movements, so they need more time to make any event. But keyboard shortcuts like these may be difficult to perform for people with motor problems because two or more keys have to be pressed at the same time, thus more than one finger (or hand) are needed. This can be fixed using the accessibility options of many modern operating systems, this 'sticky key' functionality allows separate pressing of the shortcut's buttons one by one and afterwards are interpreted as one command.

USER STORIES

All design is situated design, especially technology that is intimately used by humans to accomplish uniquely human tasks, such as communication. The sections below illustrate the

[3] **Scanning:** an indirect alternative to accessing a keyboard. Scanning uses one, two or three switches to select items from an array that is visible to the user on either the computer monitor or on a secondary display. There are a number of variations in how scanning arrays are presented to the user. Scanning arrays may use graphic images, alphanumeric characters or symbols. Scanning methods include automatic scanning, step scanning and inverse scanning. Each type of scanning may operate using one-item-at-a-time or group-item scanning. Scanning is a slow but functional keyboard alternative for individuals who are limited physically but remain able to access a single switch or an array of switches via the controlled movement of one or more anatomical sites (Bentz, 1998).

situated nature of the design space and the fact that in the particular case of individuals with disabilities the active part the user must have in the design process. A side benefit to their stories is to give the reader some insight into the day-to-day life of the exemplary end user, and thus may have a better, more realistic set of assumptions about needs and skills of the target population in creating scenarios as part of the design process (Rosson & Carrol, 2002).

The story of Xabier Madina

The designer of Etsedi system, Xabier Madina, is a Computer Science Engineer, the manager of XMadina Company since 2001, a competitive participant in the Paralympics and born with cerebral palsy. He earned this bachelors degree in Computer Science Engineering at the University of the Basque Country, in Spain. As a result he is in the powerful position of deeply understanding new technologies *and* the barriers that people with motor control problems encounter every day.

He has motor problems such that he needs a wheelchair to get around, but he can use his feet to propel the wheelchair. He has motor control problems in his hands as well and has problems to grasping or handwriting. Due to this he uses a computer exclusively for written communication. Because of having cerebral palsy he has dysartrhia as well, but he does not need any communicator. Producing words clearly enough for others to understand is an effort but he can do this.

Since completing his studies he has tracked the evolution of the new accessibility technologies. He is comfortable using many different household technologies, e.g. electrical appliances, TV, computers, and smart phone. He is able to use devices that have buttons to control (like phones, microwaves etc.), but chooses a specific device on the basis that the buttons must have adequate space between them, because when the buttons are too close he required much more time to position and press the one he desires. Because he had been using devices like this from childhood he does not require special adaptation beyond proper spacing of the controls.

He has used computers since he started his studies at the University. Because of his condition he is an expert in computer accessibility, both with respect to operating systems and input issues, particularly the special devices and systems for the people with special needs. When he started his studies computers where typically controlled using only keyboards and operating systems were based on textural commands. He always managed well in general with buttons, so he did not have problems using keyboards. His only problem was the combined key shortcuts needed to execute some actions. In these cases he ended up using different parts of his body as nose or chin. Some years later, when graphical interfaces based operating systems appear he started using Microsoft Windows® and he discovered the special configuration for accessibility with the option for executing shortcuts pressing buttons one by one (see 'sticky keys' in the section Current Alternative Approaches for Computer Input) and this enabled him to more easily perform the multiple key shortcuts. Another problem he faced with graphical interface based systems is controlling a mouse. Using a typical mouse for he was very difficult so he tried different input devices and finally found a trackball with four big buttons which suited us needs and abilities. This trackball has a big ball which he can manage using the back part of his hand. Under the trackball he put a mat to fix it to the table because when he is using it he needs to put all the weight of his hand on it and move the hand as a surface. This prevents the trackball unit from moving and allows only the ball to rotate.

The story of Mentxu and Lourdes Arrieta

Lourdes and Mentxu Arrieta are two sisters who invented a remarkable technique of augmentative and alternative communication (AAC) called “Arrieta Method”. This method consists of drawing the letters to be communicated with eye movements by the ‘talker’ and visually decoding the seen movements of the others eye (Arrieta L, 2009). This is done letter-by-letter, building up a message. When demonstrated to the authors in an interview situation information throughput was about a character every 2-3 seconds or about 4-5 words per minute.

The sisters have an estrange genetic alteration called double congenital athetosis which consists of a lack of the liquid in the medulla oblongata which blocks the motor control of their body. As a result they need to use motorized wheelchair and they have difficulty verbalizing(Abella, 2009). Lourdes cannot communicate using her voice, and Mentxu has dysarthria. Lourdes wanted badly to communicate with others and when she was a child augmentative communication devices did not exist, so she and her sister looked for a way for to communicate with others. They discovered that when Lourdes ‘draws’ (i.e. makes the same motions with her eyes that she would make with a pen to write a letter) a letter her sister could translate the movements into the letter desired and thus, his sister could understand her. They created the system as children and used it for many years. The system now trademarked as the Arrieta Method.

Both sisters were quite bright and have kept up to date with new assistive technology offerings, some of which they incorporated into their every day activities.

When they were children they were taught to produce handwriting but to do so they needed a very big pen and to put their body into as specific posture that was quite difficult to assume and quite uncomfortable. Early on they bought and used a typewriter. In 1992 they bought a computer which was used more by Mentxu because she was in the process of earning a PhD. Initially they used a standard keyboard. In the case of Mentxu was able to communicate with the computer using a standard keyboard, to control the mouse she uses the numeric keypad using the arrows as control the movements of the mouse pointer.

In the case of Lourdes, who has different mobility problems, she initially used the keyboard in a vertical position that allowed her to move her arm back and front instead of up and down because she has pain in her shoulder. Because of this pain, she cannot do exert force enough to consistently press the buttons so last year she bought a keyboard, which needed less force to execute the actions.

Currently Lourdes has an application installed in her mini-computer (also called a netbook) which she has attached to the wheelchair along with some speakers to communicate with the people. This solution is very cheap compared to the special communicators that already exist in the market, and it is perfect for Lourdes because she can easily manage with her computer, and it has a keyboard that fits perfectly to her needs. Both sisters have cell phones with Bluetooth earphone/microphones.

ABILITY AND BAND OF USEFULNESS

In considering the usability and usefulness (or value) of an assistive technology one needs to consider whether the technology, the user and the task appropriately fit together such that the user is able to effectively and comfortably incorporate the technology into their life and, equally important, whether the system is needed by the user to perform this task (see Figure 3). AT functions best in a situation where it is need to accomplish the task-at-hand and where the user can use the AT itself, this space between the upper and lower bounds is called the *band of usefulness*. The bottom bound of the band is the ability of the user to use the system, the upper bound of this band is the question of whether *this* user needs *this* system to perform the task. An example of technology that is useful to the task at hand but beyond the users capability might be a keyboard that the user would select keys with using a pointer, which would solve this users accessibility issue, but the end user in this case does not have the coordination or strength to depress the keys consistently. In this case a solution might be to replace the keyboard with a zero force keyboard (and a special tip on the pointer to trigger the sensors in place of their fingertips). In a symmetrical example consider a person who is evaluating a task support prompter to help in her day-to-day tasks. A commercially available support prompter allows the user to break down the task in arbitrarily small sub-tasks so it could accomplish her goal, but because her memory and executive function was high enough that she could memorise all the steps after several repetitions, the prompting device was soon abandoned. In this case the proper cognitive support would be a training system assisting her in acquisition of the task steps, which she could accomplish herself after several sessions. Fitting the needs and abilities of the user, the functionality and affordance of the assistive technology, and the requirements and goals of the task to be done is the first step to providing appropriate accessibility to persons with various disabilities.

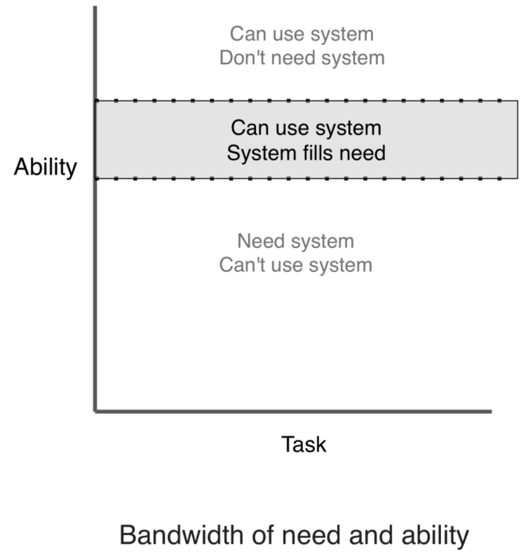

Figure 3 - Band of Usefulness

STATE OF THE ART

Here we will discuss both the state of the art in terms of research and commercially available products. Since we have constrained ourselves to character input and pointing, two theoretical approaches form the basis for thinking about this problem: Fitts law which is a model of human movement in human-computer interaction and Shannon’s work on information theory. Fits law gives us the ability to quantitatively discuss positioning and movement of a cursor on a screen, the background of all pointer studies; Shannon discusses the ability to compress data reliably and thus provides bounds for remapping keyboards to alternate methods of input from scanning to character input based on hierarchical menus.

Research

An overarching set of themes that span accessibility research and development are the approaches of universal design and assistive technology. Universal Design or Design for All describes design practices that maximise the usability of an interface by as many users with differing abilities as possible (Stephanidis, 2000). An example of Design for All in web sites are the WCAG guidelines (W3C, 2009b). However the universal design approach can only satisfice a majority of end-users, there will always be users whose needs and abilities are such that some will be excluded from even the most inclusive designs. For those users access can be obtained thru the use of assistive technology, in this case input and output supports. Assistive technologies can span from screen readers for those who have vision deficiencies to special keyboards and pointing devices for those with motoric disabilities (W3C, 2009a).

Another way of approaching this problem is to change the content or to provide good guesses as to the intent of the end-user. The former approach is the basis for the alt text tag and other output approaches in the accessibly attributes that are specified in the WCAG standard (W3C, 2009b). Changes of the content to accommodate input modality include the use of radio buttons to replace text entry and value entry to replace difficult top use sliders. Technology that guesses the intent of the end-user transform a wholly character entry task to abbreviated text entry and selection of options using word prediction technology. These types of guessing and prediction support can provide assistance to both motoric and cognitively challenged users.

Researchers have brought these two approaches to the problems of character entry and pointing. One excellent example of applying quantitative research tools to the design of alterative input systems explored providing guidance to pointing systems thru guessing intent and providing nudges toward possible goal thru Haptic feedback(Hwang, 2001). Work on alternate character entry has explored using trackballs for text entry using novel encoding of movement (Wobbrock, 2006) while others have used data compression in the form of levels of menus reached by pointing devices.

Commercial offerings

Accessibility research has traditionally focused most of its attention on output, especially with respect to HTML and web site technology. This is possibly because adapting output, which typically is visual (while acknowledging the smaller part that auditory output takes, mostly in the form of bells and auditory alarms), entailed a fairly straight foreword task of switching modalities with some additional content needed to support the switch (i.e. alt text tags). The resultant web page is now accessible with jaws or Braille. Interestingly visual disabilities most often occur in the dimension of resolution (i.e. the 20/20 standard and contrast / brightness. Rarely is a visual problem based on jerkiness or loss of muscular control of an eye or the coordination between eyes. This is fortunate as this ability to focus and track coherently is a critical determinant in the use of eye-based forms of input assistive technology.

The requirements for assistive technology for output accessibility resulted in adaptations such as screen magnification, switching to auditory modality (e.g. Jaws) or to haptic modality (e.g. Braille). However output without providing appropriate affordances for input is ineffective in providing real accessibility, especially in the context of comorbidity as discussed above. Therefore, to support people in their desire to engage the world we need to pay attention to supporting as many accessible forms of input as possible.

Typical ontologies of assistive technology for accessibility focus on persons. The most efficacious way to do this is to focus on the persons functionalities and needs and not to the underlying disease (Carmien, 2007), a good example of why this is so is that a pathology (say cerebral palsy) may require different assistive technology to provide equal levels of accessibility. Because of this a functional approach to analyzing AT provides better support to both AT designers and to professionals in guiding the selection and configuration of AT.

That said, this chapter will however focus on AT from the computers perspective. This kind of typology perspective allows us to work form the bottom up in creating useable input adaptations. So, while acknowledging the growth of novel input strategies of systems like Ambient Assisted Living (known as AAL) (Kleinberger, 2007) there is a need to concerning ourselves with conventional pointing (e.g. mice) and character (e.g. keyboard) input for which existing switching of sensory modality s will not be sufficient, either due to pathology (e.g. persons with cerebral palsy who cannot speak clearly enough for voice recognition and whose lack of fine muscle control prohibits use of even large keys keyboards and giant trackballs), or to bandwidth requirements (i.e. applications that require pointer input faster than can be provided by speech recognition).

Figure 4 - Touchpad as Keyboard

We can divide the modalities of computer input into command input and pointing (within a desktop metaphor). There are of course other forms of computer input, such as digitized analogue signals (music) and specialized keyboards such as musical and directional, touch screens (which are a isomorphs of the pointing problem) and hardware buttons, such as on a PDA (which can also be mapped to a screen and thus become another isomorph of pointing). However, for this discussion, we will only examine the two described above as they account for the majority of instances of interaction that a person with functional disabilities requiring alternate ways to interact with a computer.

First we will discuss character input or command input. The encoding of commands is typically via ASCII or Unicode, which can themselves be encoded into hierarchies of options that allow selection of characters either by traversing a tree or by presentation of possible inputs for selection (scanning). Examples of selection of character are the various scanning systems, ranging from eye tracking systems to physical selectors such as large buttons, sip & puff techniques, shadow switches, tongue switch, tip switch, and EMG/EEG[4] driven switches Keyboard input can be utilized with the use of specialized keyboard triggering techniques ranging from mouth sticks and head wand, sticky keys, zero force keyboards, and specialised keyboards like those with oversized keys and those tightly integrated with their application like the DynaVox devices for AAC. There is a degree of symmetrical overlap between keyboard alternatives and pointer alternatives, consider on screen pointers to soft keyboards and keyboard arrow keys to controlling cursors.

[4] **EMG** - Electromyography is a technique for evaluating and recording the activation signal of muscles; EEG - Electroencephalography is the capturing of electrical activity along the scalp produced by the firing of neurons within the brain.

The details of pointing techniques are more complicated than character entry because characters are discrete values and pointing is (potentially) a vector with infinite directionality on the 2d plane. However this problem can be made tractable by reducing the pointing vector to be based on only 4 directions and arbitrary small lengths of incremental movement. There are two basic approaches to pointer input: mouse like devices and replacing pointing with vectors. Mice like devices span trackballs (both standard and oversized), direct interaction with the screen via touch screens, discrete interactors like keyboard arrow keys and speech control.

Finally there are alterative input frameworks beyond the keyboard and desktop metaphor (Dourish, 2001). Examples of this include the work done in tangible computation and direct interaction (beyond touchscreens). These can range from large physical buttons to computationally enhanced tabletops to embedding physical objects with computational significance (Arias *et al.*, 1998) to natural speech interaction.

DESIGN OF THE *ETSEDI* SYSTEM

In this section we will talk about the process of design of the word predictor based on a virtual keyboard distributed in a matrix of nine buttons. Then this virtual keyboard was adapted to be used in different applications and with different input devices. In this section the evolution of the system will be analyzed.

Directional selection approach

Directional selection system is based on the action of identifying different orientations among eight different virtual areas in the plane.

Figure 5 - Translating Direction Into Joystick Commands

Directional selection is based on the movements of a joystick which has the start point in the centre (relax state), and has eight simple movements: up, down, right, left, and four diagonals. Motor wheelchair control is based on joystick and typically people even with strong physical disabilities can drive the wheelchair using directed movements. This is an existance proof of the possible capabilities of people with motor impairments. People with motoric dysfunction in their arms and who need to use a wheelchair usually do not have problems using a joystick for navigating, so we extrapolate from this that they can do directed discriminations in the plane with an acceptable accuracy ("*Dorland's medical dictionary*"; Madina X, 2004). The design of this system for computer input is based on directional selection taking into account that the population with cerebral palsy or a similar disease which affects motor control usually affects upper and lower limbs. Given that the joystick is accessible to the populaiton who have problems with character selection and pointer positing and item selection what follows is a discussion of the mapping of the potential of the joystic to the input accesibility problem.

Design

One problem that people with manual motoric disabilities is that the usual input devices we use for computers are not accessible to them. Mice need fine control in hands and arms to be used, and keyboards are often difficult to use because the keys are very small, are very close to each other and manual control and pressure to be successfully pressed. To solve this problem many special devices have been designed, including different types of virtual keyboards for typing text, which can be used with pushers of various kinds.

In the beginning of the process of designing the Etsedi system, many different exiting input adaptations were looked at. A lot of these systems were based on scanning which is a common yet ponderously slow technique. This is very useful for the people with severe motor problems and people with extremely low mobility in their hands, arms or fingers. But in the case of the designer of Etsedi, like other potential users, had some motor control problems but he had more functionality than only being able to move his hand to press a button and systems which use scanning were extremely slow in throughput. He found different systems and algorithms to optimize scanning, but all of them were slower than using other input devices. Because he perceived a gap between needs and abilities for people who had some motoric difficulties who could not use a standard keyboard but not so much that they could only use scanning, he decided to see if a joystick based solution would be appropriate for those people.

Taking into account that the people who use to drive a wheelchair can easily control a joystick he started exploring the design pace based on the use of a joystick. The resultant initial design consisted of a virtual keyboard based on a matrix of nine buttons (3x3) where all the letters of the alphabet were allocated along the buttons except in the middle, which was valueless and was used as a reference or starting point.

The path of execution of the application starts with the letters of the alphabet were divided in groups of three or four letters and displayed in the nine outer squares. When the user moves the joystick pointer to one of these squares the system makes a guess as to the word and placed these guesses in the outer 14 squares in the next encircling set of squares. The guesses for the words are based on a word frequency table (word prediction) and the set of possible letters chosen so far. If the outer squares have the desired word then the user navigates to the word with the joystick and the word is output to the selected application (in this case MS word). If the user has reached the end of the sequence of letters making up the desired word and does not set it in the outer squares, by clicking on one of the empty squares the system then presents the first set of 3-4 letters in the 9 middle squares and one by one the user can select the exact set of letters that make up the word she wants. As part of finishing out the spelling of the word, the system adds the word to its word prediction database.

Lets go through spelling ‘Carrie’ first the user goes to the ‘ochz’ square selects it. At this point the outer squares fill up with predicted words, none of which are ‘carrie’. The user next select the ‘abvñ’ square and again the outer squares fill up with predicted words, none of which are ‘carrie’ The user then repeats this with the ‘rfk’ square and again with the ‘rfk’ square the with the ‘imn’ square, and finally with the ‘dej’ square and carrie’ does not show up in any of the outer squares. The user then selects one of the empty squares (there is always at least one empty square) and the display changes to the one in figure 6 on the right, allowing the selection of the individual letter out of the set. The user goes through all the sets of letters (i.e. ‘abvñ’ ‘rfk’ ‘rfk’ ‘imn’ and ‘dej’) and select **those** individual letters and the system outputs ‘carrie ‘ in the linked MS Word open document. As part of the final process when a word is spelled out it is inserted into the word prediction database so the next time the letters in the word ‘carrie’ are selected ‘carrie’ comes up in the outer squares, allowing the user to select ‘carrie’ without spelling out all the letters. What sounds like a cumbersome and complex system of spelling out a text word is in use many times faster than traditional scanning.

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Figure 6 – Grouped letter grid (left), middle of letter selection process (middle), individual letter of group selection grid (right)

At the beginning a dictionary of 80,000 words in Spanish with the frequency of use of the words was used. From 80,000 words, it was decided to work with 10,000 words, which are the most used ones, to be more efficient. This dictionary was divided among the number or characters of each of words, and he discovered that the length of the “X” word, the number of words with the same length in the dictionary was less or equal as the possible combinations of the keystrokes of “X” word ($8^{len\ X}$). A fortunate Spanish language attribute is that about 60% of the words typically used in Spanish have 6 or less letters, and almost 35% of the words have 1 or 2 letters (Madina, 2002); this may have design implications for languages with much longer high frequency words, like German .

One problem of this design was that the functions to delete letters or words or to undo actions were missing, and in a 9-button keyboard where 27 letters were distributed there was not enough space to add more functionalities. But the action of deleting was really important in this kind of interface, because the potential users of these systems have motor control problems, so it is very common to press a button which they did not intend to press. For this reason it was decided to add some buttons around the 3x3 keyboard.

The functionalities added were located in the positions which can be easily accessed:

- Up – delete word
- Right – delete (for one character)
- Left – Enter (add a new row)
- Down – White space (the system will add a white space after a word automatically, but if the user wants to add another one, can do it using this button)

Delete a word was considered as a very useful function because for the people with motor control problems, accessing a button can be a big effort. So they should save time using this button in order to delete a word character by character.

This design was hardcoded to work as part of Microsoft Word® program because it has can have a voice synthesizer to read the text the user is writing to communicate with others as well as it’s text editing function. Microsoft Word® offers a lot of different functionalities, but Etsedi program was designed to control only some of them (the most used functionalities): open file, save file, selection of text, copy, cut and paste text, go through the text, zoom of the text, and a few others. Two menus were added to give the option to input numbers and some symbols (brackets or quotes, for example).

Alternative design

At the beginning this application was designed to be used by the people with motor control problems in using the mouse or a trackball as an input device. Most people with moderate to severe motor control problems are not able to use the mouse because of the level of precise movements it requires, Etsedi design supports the user in getting access to different actions with small movements which can be controlled more easily.

Etsedi can also be used with a regular mouse or trackball (there is a demo versions that does just that). Sometimes, people with motor control problems have a muscle spasm which cannot be controlled by them. To solve this problem when a mouse is used the design included a restriction for the pointer of the mouse: it cannot go out of the menu. Using this restriction, when the user has a spasm he does not have to recover the position of the pointer which may take significant amount of time.

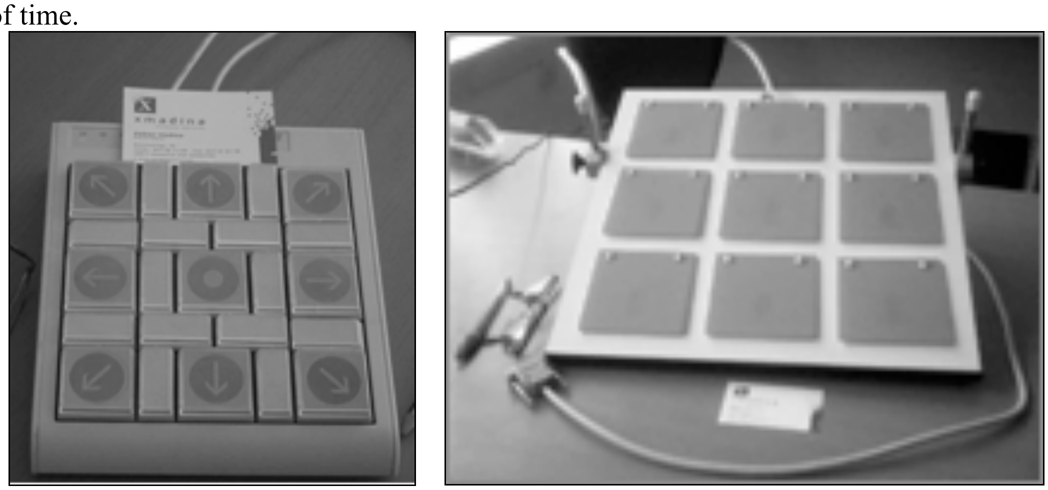

Figure 7 – Sedikeys (left) Ernest (right)

When first iteration of the system design, the designer realized that this kind of application will be used by people with very specific needs, and in this kind of population each person has different needs.

For this reason he decided to add several different ways to input the Etsedi system. Initially the application could be used with all the different input devices which can control mouse pointer: trackball, joysticks, head mice, eye trackers, etc. But taking into account people with motor control problems who use numeric keypad to control mouse pointer using the buttons as simple movements on the plane. In the case of numeric keypad it has 10 buttons. 9 of them are distributed into a matrix of 3x3, like Etsedi, and the 10th button is bigger than the rest (it corresponds to the number 0) and it is located in the 4th row occupying first and second columns. Looking at the similar aspect of two keyboards it was decided to configure Etsedi system to have the possibility to be used with the numeric keypad[5] using the numbers 1 to 9 as movements and number 0 or 5 as a mouse click (executes the action)

[5] Note that the hardware described in this sections only for *navigation* around the virtual keyboard, i.e. to reach the outer squares in Figure 6 (left and centre) you would press the arrow keys twice.

Looked that numeric keypad was too small for some of people, it is inaccessible because the size and layout of the keys. For this reason some hardware designs were done with bigger keys. This is the case of Sedikeys keyboard. This keyboard is based on an industrial keyboard which is divided into a matrix of different points. Those points can be grouped or divided, personalizing the keyboard. In this case this keyboard was divided to have 9 big buttons in a similar distribution as numeric keypad.

Another design based in the same principle was Ernest which was designed to be used by feet.

After working with these different access technologies for the system some potential users asked to have scanning added because some people with motor problems do not have the ability to use any other kind of access. The design of Etsedi was a good candidate for scanner control because it was a symmetrical matrix. Scanning can be done offering the user the options one by one which can be very long process if there are too many options and the one that the user wants to execute is the last one. But other way to work with the scanning is to divide the options into a matrix and offering to the user row by row, and when the option that the user wants is into the row is offered, the user presses a button and then the options of this row are offered one by one. In this last case the clicks are needed are more (two for each event) but the time is needed is usually less. We will see an example with 9 buttons:

1.-

1	2	3	4	5	6	7	8	9

2.-

1	2	3
4	5	6
7	8	9

Figure 8 – Buttons in row/buttons in matrix

If presenting each option the system expends 2 sec. and the action that user needs is one ninth of the time is needed in each case is:

Option 1 → 2 sec * 9 = 18 sec

Option 2 → 2 sec * 3 (rows) + 2 sec * 3 (columns) = 6 + 6 = 12 sec

In the case that the action wanted by the user is the first one, it is the only one where the time expended is more (**option 1** = 2 sec, **option 2** = 4 sec). But in the rest of the cases will be the same or less. We will take a look to the event number 5 (the one is in the middle):

Option 1 → 2 sec * 5 = 10 sec

Option 2 → 2 sec * 2 (rows) + 2 sec * 2 (columns) = 4 + 4 = 8 sec

Taking into account that the optimum design of the Etsedi keyboard was done because all the events were distributed into symmetrical matrixes adding the option of scanning was very easy to implement. The time that the system is offering each option should be personalized by the user this access option in Etsedi system has different configurations which can be changed from 0.5 sec to 5 sec, being default option 2sec (the most used one).

Other access configuration which has been added is the click by time. Some people can control the movement of the mouse but do not have enough strength to do click with the mouse, or the people who use head mice or eye trackers need a special system for doing click. Etsedi system has another configuration option for doing click maintaining the mouse pointer stopped on a button for some time. The time is needed to be a click can be personalized by the user and it can be changed between 0.5 sec. and 5 sec.

System integration

The designer won a prize from Kutxa (a regional bank with a corporate policy of sponsoring accessibility design) with the Etsedi system in 2001. With the money of the prize he founded XMadina to develop systems for people with motoric disabilities. In 2003 the company won the second prize of the XIV Toribio Etxebarria (a Basque country design prize) with the same design.

In reviewing the state of AAC and alternative input technology XMdadina research revealed that while there are other systems of alternative input for those with motoric disabilities, most of the work done in alternative input systems for environmental controls (e.g. heating, lighting, entertainment) is currently in the research and standards communities (the V2 project (trace.wisc.edu, 2005) and WWC device independence initiative (W3C, 2005)). So in 2001 the XMadina team worked with real users to discover the kinds of applications most important to them in their daily lives. These discussions revealed that people with motor control problems have most frequently problems using remote controls of usual devices as TV or HI-FI systems, and mobile phones. The controls of these devices have a lot of buttons, and as a result they end up being very small and were laid out tightly; further these users did not use the functions that the majority of buttons activated, and were quite swilling to trade off fewer functions (and thus buttons) for a useable system. So the Etsedi interface was ported to these systems, specifically in two special applications: 1) controlling a TV using a TV card connected to the computer, and 2) for controlling music and videos using Windows Media Player®. Those applications were called SDTV (Selección Direccional TV – Directed Selection TV) and Discaplay respectively.

Both applications are based on the design of Etsedi: 9 button input interface distributed in a 3x3 matrix. Only the main actions of the program were taken into account because the space of the interface is very limited and because the design is based on the notion of supporting the set of most used functionalities and thereby making the application useable. These actions included volume up and down, play/pause and stop or next and previous (channel up and down in the case of TV).

Another problem for the people with motor problems is the use of telephone and smart phones. Again, typically the buttons of the phones are very small and are too close. But the use of the telephone can be especially critical for this population so that they can communicate with friends, family, doctors, or to ask for help. For this reason Etsedi design was applied in an application which could be used to control the functions of mobile phones. In this case, the mobile phone is connected to a computer using a USB cable or Bluetooth, and can then be controlled through the PC. The application, TaseMobile, supports controlling a set of events through the users PC: placing a new call, receiving a call, send, receive or manage short text messages (SMS) or managing their phonebook. Only these main actions were taken into account because users revealed that they were the most used ones. In the case of building text for short messages the word predictor from the original Etsedi design was adapted.

Recently the trend of cell phones is towards smart phones most of which include touchscreens and virtual buttons in the screen. The size of the screen is not very big, but this kind of input interaction gave us the option to optimise the design of the size and the shape of the buttons for our target population. Applying the Etsedi design, different applications for smart phone devices were created. The TaseMobile application was a good fit for the user if she were at home, but if she wanted to go out then her mobile phone remained inaccessible which defeated the advantage of portability, and, more importantly the constant availability for the user. TaseMobile was adapted to be used with the touchscreen of the device. Because of the small size of the touch screen precluded using the 3x3 input grid of Etsedi, the scanning approach described above was utilized, with the entire touch screen used as the only button.

Smart phones give mobility to the user, and often are designed with 1) general computational ability that can be tapped into and 2) a speaker system designed to be used as a speakerphone. People with cerebral palsy often have dysarthria and have difficulties communicating with others, especially with people unaccustomed to their conversation idiosyncrasies, because they are frequently quite difficult to understand. These individuals with dysarthria may use AAC communicators to bridge this gap. There are a lot of different communicators in the market, but most of them are very expensive (more than 3,000€) and too large to carry around conveniently. Smart phones are portable (most of them are small), and designing and coding an application to be integrated into a smart phone should not be very expensive. So using Etsedi design with word predictor and adding a voice synthesizer XMadina got a portable communicator, called Etsedi PDA, easy to use for the people with motor impairments.

Trials

This system was not formally tested, but it was presented in different conferences and workshops were the users could try it and see what are the things must be changed in this system.

One big problem of the system and which should be fixed is to apply this design to free distribution operating system and applications. Before applying the design to different applications a research about the most used applications and systems in Spain was done. The result was that the most of the users who was designed this system were using Microsoft Windows© operating system, so it was applied to it and the applications are running on it. This is the reason because this design is not prepared to work in other operating systems like Ubuntu, MacOS, Mandrake, … Some of the users who tested the system asked for an adaptation of it to use it in different personal applications they had. The easy adaptation of the system is very important for the users, so this should be an important future work for this system.

CONCLUSION & PLANS FOR FURTHER WORK

In this chapter we have reviewed motoric disabilities and computer input from a pathological and functional perspective, and hopefully have given a prospective AT designer a use full perspective on causes, parameters and potential solutions. The authors would like to emphasise that no amount of formal study will replace actual experience with end users and their work practices. The domain of computer accessibility is complex and the needs of various users extremely varied, nonetheless approaching the issue within the frameworks described in this chapter may allow the designer to build upon a strong foundation of experience and successful examples.

People with motor control problems typically would access computers using special devices or virtual keyboards with scanning systems. Scanning is a very useful approach, but people with some mobility in hands and arms, but who also have control problems typically find scanning very slow. It is for this reason the Etsedi system was designed. Using this system people with motor control problems can write texts with mouse, trackball or joystick movements quite quickly due to clever menuing combined with an effective text predictor. The special design of Etsedi system was easily adapted to use with a scanning approach that can be adapted for people with special needs while retaining the advantages of word prediction. Beyond text production Etsedi has been adapted to other kinds of applications for leisure (e.g. TV or HI-FI) or for communication as an AAC communicator, or to control a smart phone.

Currently Etsedi has been adapted only for the applications mentioned above but may be of great benefit if adapted for more. In the future this system could be ported to other operating systems, such as MacOS and Linux and made less application dependent and more of an integral part of the OS's accessibility functionalities.

The Etsedi system was adapted to be included in some smart phones with touch screens to work as communicator. Many smart phones currently include multiple wireless communication protocols and hardware (infra-red, Bluetooth or Wi-fi) which could be used to communicate with the environment using smart phone as a remote control. The Etsedi system could be adapted to work as a remote control for domotic controlling different devices as DVD, air conditioning system. In a larger context Etsedi could be easily adapted to be used with any kind of application which requires a keyboard or remote control, to facilitate the access of persons with motor impairments to gain equal access to smarthealth care of the ambient intelligent environments(Aarts, 2002) of the near future.

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KEY TERMS & DEFINITIONS

Support systems: System to provide access to technology that support the use of it, Support system scan be direct (i.e. a piece of technology) or indirect (i.e. an accessibility interface to a piece of technology)

Motoric dysfunctions: A loss or limitation of function in muscle control or movement or a limitation in mobility. This may include hands that are too large or small for a keyboard, shakiness, arthritis, paralysis, and limb loss, among other difficulties

Augmentative devices: Any device that facilitates communication by those with limitations

Scanning: An indirect alternative to accessing a keyboard. Scanning uses one, two or three switches to select items from an array that is visible to the user on either the computer monitor or on a secondary display. There are a number of variations in how scanning arrays are presented to the user. Scanning arrays may use graphic images, alphanumeric characters or symbols. Scanning methods include automatic scanning, step scanning and inverse scanning. Each type of scanning may operate using one-item-at-a-time or group-item scanning. Scanning is a slow but functional keyboard alternative for individuals who are limited physically but remain able to access a single switch or an array of switches via the controlled movement of one or more anatomical sites (Bentz, 1998)

Assistive technology: Technology that promotes greater independence by enabling people to perform tasks that they were formerly unable to accomplish, or had great difficulty accomplishing, by providing enhancements to or changed methods of interacting with the technology needed to accomplish such tasks.

Universal Design or Design for All: Design for All (DfA) is a design philosophy targeting the use of products, services and systems by as many people as possible without the need for additional mediating technology (e.g. assistive technology)

Accessibility: Accessibility refers to the practice of making technology, particularly computer based technology, websites usable by people of all abilities and disabilities. It may also be used as an adjective describing the degree to which a product, device, service, or environment can be accessed.

Directional selection approach: An alternative to pointing devices like mice which allows a disabled user to indicate the direction she wants the cursor to move on the screen; typically used for selection of options. Typically based on identifying different orientations among eight different virtual directions in the plane

Computer input: Any peripheral used to provide data and control signals to an information processing system.