DAWN EXPLORER: A FRAMEWORK FOR MULTIMODAL ACCESSIBILITY TO COMPUTER SYSTEMS

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ABSTRACT

Technology is advancing at a rapid pace, automating many everyday chores in the process, changing the way we perform work and providing various forms of entertainment. Makers of technology, however, often do not consider the needs of the disabled in their design of products by, for example, providing some alternative means of input. The use of computers presents a challenge to many disabled users who are not able to see graphical user interfaces, use a mouse or keyboard or otherwise interact with standard computers. This paper presents a multimodal user interface, emulating and extending the functionality of the Windows Explorer application, with alternative input and output methods. The project utilizes auditory and visual interaction technologies, comprises a modular and extendible architecture and utilises off-the-shelf hardware to reduce implementation cost and maximize accessibility.

KEYWORDS: *Auditory interfaces, GUI, multimodal interfaces, blind, visual impairment, audio, human-computer interaction, interface models, rehabilitation engineering, users with special needs, disability*

1. INTRODUCTION

1.1. Computer Accessibility Issues for the Disabled

Previous research has established that working-age disabled people are significantly more likely than non-disabled people to be unemployed or under-employed. An increasing proportion of useful commercial and social information (such as online banking, shopping and news) is available online or otherwise accessible on computer systems. For a blind person, in particular, the use of a standard computer, with graphical display and traditional input methods, is simply not an option. All disabled people face particular challenges using these electronic services - for example, cost, access difficulties and unfamiliarity with electronic technology. These limiting factors can be exacerbated for older age groups to which many disabled people belong.

Key factors driving development in the area of accessibility for users with disabilities are demographic changes and the ageing population, legislation introduced by government, including the United States of America (USA) and the European Union (EU), as well as the realization of the increasing diversity of people requiring access to information technology.

A survey carried out by the Leonard Cheshire Charity in 2002 (Joseph Rowntree Foundation, 2004) found that 54 per cent of the disabled people in their sample considered Internet access essential, as opposed to only 6 per cent of the general population. Additionally, 48 per cent of disabled respondents to the survey said that going online significantly increased their quality of life, compared with 27 per cent of the general population. This is because there are often practical barriers to disabled peoples' participation in society which can be overcome through computers and the internet.

While about two-thirds of disabled computer users taking part in a recent study by the Joseph Rowntree Foundation (2004) did have aids or equipment adaptations to access a computer available, almost half were experiencing problems using them. Others did not have the aids available to them, which they felt they needed, and still others did not know what they would need to effectively access a computer and the range of services and information which they could take advantage of.

1.2. Overview of the Dawn Explorer Framework

It is highly desirable to provide blind and visually impaired persons with an easy means of access to a standard PC that does not require specialized equipment. The access should in particular allow the easy navigation of the file system. In this paper we introduce a file system navigation utility similar to the Windows Explorer application for the *Windows XP* operating system. The files and directories are distributed on a virtual screen (see Figure 1 and 2) and are signified by auditory, rather than graphical, representation. Central to the application framework is the abstract pointer, able to interface with any number of interaction mechanisms ranging from the common mouse to motion tracking technologies, along with sound effects, voice synthesis and third-party assistive technologies, such as Braille devices.

According to the U.S. Department of Education (2005), specially adapted hardware and software for the blind and visually impaired has always been expensive and unfortunately this trend is continuing if not worsening.

The Dawn Explorer project avoids specialized hardware, instead focusing on off-the-shelf, common hardware components easily available to all computer users. Modern personal computers are equipped with powerful programmable graphics processing units (GPU). To relieve the central processing unit (CPU) and increase responsiveness, the system will in a future implementation perform the vision processing tasks on the GPU instead of the CPU, as blind people are unlikely to use applications demanding heavy graphics processing. Web cameras and speaker systems are usually included with new computer systems or can be purchased at low cost. These readily available technologies alone represent the basis for a fully functional Dawn Explorer-based interaction system.

The remainder of this paper continues with an overview of the social implications of accessibility to technology in Section 2, followed by a brief review of available technologies in Section 3. Section 4 contains a description of the Dawn Explorer application framework, and the paper concludes in Section 5 with a mention of future work necessary to further enhance system functionality.

2. SOCIAL IMPLICATIONS OF ACCESSIBLE TECHNOLOGY

The Australian Federal Government (2004) reports that people with disabilities make up 20% of the population. However, as the above figures only consider persons with a profound disability, actual figures are estimated to be closer to 35% of the total population suffering from some disability of varying degree at some point during their life. This hidden percentage would incorporate:

- those with a temporary yet "significant" disability
- those recovering from an operation or illness
- those who do not qualify for a pension because their assets are above the required limit
- those individuals living with their disabilities without claiming a disability pension
- visitors to Australia

As we age, our chance of living with a significant disability rises. By the age of 75 we have a 68% chance of having a significant disability. In the EU, currently more than 80 million people are older than 60, a number expected to increase to 100 million by 2020. The proportion of the population of the EU living with a disability is predicted to rise to 17% by the year 2030 (Eurostat, 1995). Similar figures are available for the USA, where the US Census Bureau (1997) quotes 20 % of the population as living with a disability. The number of US citizens above the age of 65 is expected to exceed 22% by 2030, while the "over 85" age group is currently the fastest growing (Howell, 1997). It is accepted that most individuals, who live over the age of 60, have an increased likelihood of experiencing some form of disability or functional limitation.

Those living with a disability are also somewhat disadvantaged in their search for employment. According to the Australian Federal Government (2004)

- 53 per cent of people with disabilities between 15 and 64 years were employed in 2003, compared with 81 per cent of people without disabilities.
- 8.6 per cent of people with disabilities were unemployed (that is, they were actively seeking work) compared with 5 per cent of people without disabilities.

These figures highlight the inherent reluctance of the business sector to employ individuals suffering from a disability due to the relatively high cost of providing access to facilities, including computing facilities.

3. ASSISTIVE TECHNOLOGIES AVAILABLE TODAY

A majority of persons with disabilities can now lead more independent lives in their communities, attend regular schools, and seek professional careers than ever before in history. Assistive technology providers have changed their focus from people with disabilities as requiring treatment and intervention, to a view of the person with a disability and the minimization of obstacles to living in the community and participating in the workforce. Assistive technologies have been an important key to successful community participation. However, the rate of assistive technology non-use, abandonment and discontinuance remains high - the average being about 1/3 of all devices provided to consumers (Scherer, 1998, 2000, 2002; Taylor and Francis Group, 2002; World Health Organization, 2001).

ABLEDATA (2005), the assistive technology product database sponsored by the Institute on Disability and Rehabilitation Research, U.S. Department of Education, reports approximately 22,000 current products from over 2,000 different companies available to users with a disability. However, the vast majority (>95%) of products listed are specialized hardware devices aimed at specific disabilities. These are expensive, often hard to handle by the disabled person and only available from specialized vendors. Software solutions comprise less than 5% of total available products and are typically aimed at specific disabilities, usually screen readers for the blind or visually impaired and learning solutions for intellectually disabled computer users.

Traditionally, software and hardware tools for visually disabled users have essentially been implemented as text-based interfaces, which return information in the form of voice synthesis or Braille in combination with keyboard control. Studies have shown the importance of preserving the intrinsic spatial constraints of GUI's (Stephanidis, 2005), while using auditory feedback to create a virtual representation of the graphical interface and its components, such as windows and icons (Tominaga & Yonekura, 1999; Myatt & Edwards, 1992).

Ramstein *et al.* (1996) reports that assistive technologies enabling human-computer interaction for users with a disability often require some additional hardware, which is either worn or manually operated by the user. This additional requirement adds expense and inconvenience for the user. Dawn Explorer aims to use off-the-shelf hardware, a multimodal interface and an abstract pointer to interpret the users' gestures to interact with a virtual computer interface.

4. THE DAWN EXPLORER APPLICATION FRAMEWORK: DESIGN AND IMPLEMENTATION

4.1. Requirements Specification

The aim of the Dawn Explorer project is the delivery of an inexpensive and accessible user interface to benefit all users with a disability, and as such society as a whole. As explained in Section 1.2, a convenient file system navigator can be realized by manipulating an abstract pointer on a virtual screen.

4.1.1. Abstract Pointer Control

The abstract pointer is a representation of the user's immediate area of focus in the virtual screen. Movement and manipulation of interface components can be initiated using the input method of the user's choice. These may include, but are not limited to

- mouse
- joystick
- trackball
- microphone
- motion tracking
- third-party assistive input technologies

4.1.2. Abstract Pointer Localization

At any point in time, while navigating the virtual screen, the user should be able to accurately determine the location of the abstract pointer. Due to the multimodal design of the Dawn Explorer framework, several options are available:

- auditory, using sound effects and speech synthesis
- Braille devices
- third-party tactile output technologies

The choice of feedback depends on the user's preferences and abilities, but is not in any way limited by the application framework.

4.1.3. Virtual Screen

The application interface layout facilitates the various interaction technologies utilized by Dawn Explorer, as well as their application in providing blind and visually impaired computer users with accessibility and usability of the Windows XP operating system enjoyed by sighted users.

The Dawn Explorer interface aims to be a best-practice design conforming to internationally accepted accessibility standards. Relevant information sources to be taken into account are books, style guides, technical reports and standards published by recognised standards bodies and organisations (ISO, 1998, 2002; Apple Computer, 1995; Stephanidis, 2001). Note should be taken that the application utilizes an auditory interface and not a graphical interface on a screen for user feedback. This means that many of the guidelines and recommendations usually applied to graphical interface components, such as icons and windows, have to be transposed to an auditory interface using various sound effects and voice synthesis mechanisms.

4.1.4. Software

- Integrated speech engine technology is a stock version already integrated in Microsoft Windows XP operating systems. Also available is an intuitive training component, enabling customization by and adaptation to individual users. The aim is to raise the level of usability and accessibility of the application to a standard experienced by sighted users. Common menu commands are accessible through equivalent voice commands, eliminating the need to drill through multiple layers of sub-menus.
- Sound effects are generated using available Windows XP interfaces
- Motion tracking algorithms are implemented in the .Net framework
- Input devices connected either by USB or serial port can be accessed through the DirectInput API (part of the DirectX SDK) or COM Interop technology

4.1.5. *Hardware*

Hardware requirements are to be kept minimal. Users should have the option of using the standard Dawn Explorer system, which only requires a microphone and speakers for the auditory interface and a web camera for motion tracking. However, the possibility of connecting third party assistive technologies exists, eliminating the need of having to purchase any new equipment.

4.2. *The Current Implementation*

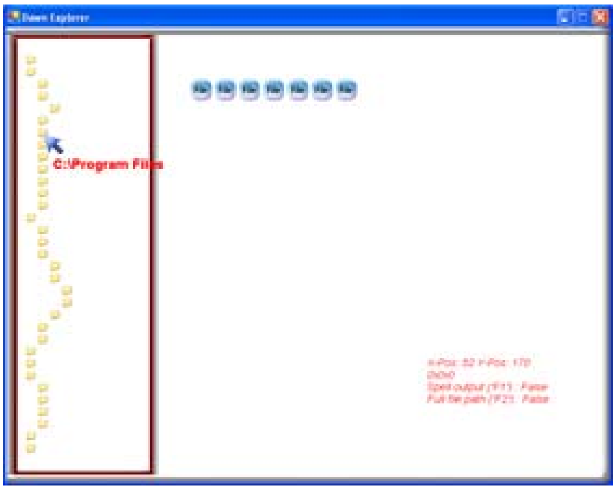

Figure 1: Directory selection. The left pane of the virtual screen matches Windows Explorer design.

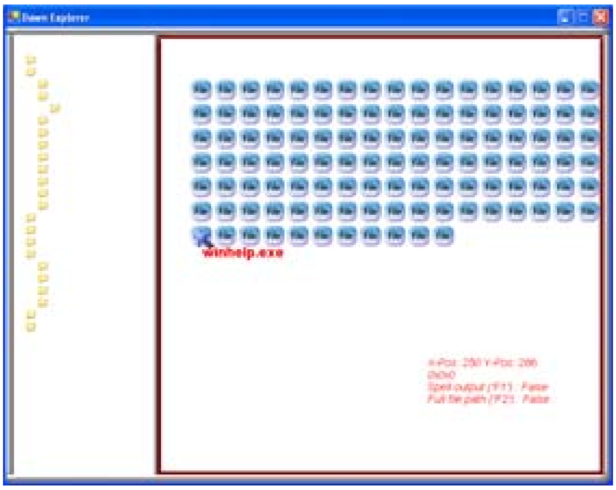

Figure 2: File selection. When the abstract pointer hovers over an icon, the corresponding file name is read. Spoken command may also be issued to manipulate the file (for example open, cut and paste operations).

4.2.1. *Abstract Pointer Control*

The abstract pointer currently interprets signals from the common input devices (mouse, joystick and game pads) to interface actions. Of note here is the fact that the abstract pointer interfaces with the DirectInput API (DirectX 9 SDK) to catch events, such as moves and button-clicks generated by the hardware devices.

4.2.2. *Abstract Pointer Localization*

Whenever the pointer hovers over any file icon, the system reads the file- or directory name aloud. Optionally, the user may have the name spelled, if speech synthesis proves difficulty to understand. Moving the abstract pointer around the virtual screen generates a slight ticking noise, which changes in sound and frequency as it moves into and out of the vicinity of other interface components.

The environment around the abstract pointer may be explored, with the system ‘whispering’ the names of files located in the immediate vicinity, while other interface components, such as the interface borders, generate a unique sound when the abstract pointer makes contact.

4.2.3. *Virtual Interface*

In its current stage of development, Dawn Explorer successfully implements features and functionality of one of the fundamental applications of Windows XP, the Windows Explorer file system navigator.

The spatial constraints of the interface are restricted to the window borders and enforced by playing a sound when the abstract pointer touches a border, as well as stopping any pointer movements. Interface components dynamically react to the abstract pointer by generating sound effects when touched and reading their respective component names when the user so chooses.

It should be noted that the graphical display is at this stage of the development cycle mainly utilized for demonstration and testing purposes. In a future implementation use of the graphical display will be optional for visually impaired users, who are not completely blind. This can be in addition to other interface options facilitated by the Dawn Explorer framework.

While currently roughly ¼ of the screen area is occupied by a fully functional representation of the file system tree the final implementation will provide users with other means to navigate to directories and files (like a 'Favourites' list). Around ¾ of the screen is occupied by the contents of the currently selected directory. Individual files are represented as icons, the names of which are spoken, and optionally spelled, to the user.

Dawn Explorer uses a rule-based text-to-speech engine, which involves the modelling of speech using a set of established rules, such as acoustic analysis and phonetic theories. Rule-based synthesis has attained highly intelligible speech quality and presently already serves in many practical applications (Allen, Hunnicut & Klatt, 1987).

Speech recognition and synthesis technology is utilized to enable interaction between the Dawn Explorer interface and the user. An example of action already implemented in the current version is menu navigation, which almost takes the shape of a conversation. The user may ask for menu choices. Dawn Explorer, based on the current context, makes a decision about the most appropriate choices it should present. These choices are read aloud to the user, who is then able to respond with the voice command of his choice. The menu structure is designed to generate dynamically and to avoid nesting menu choices more than two levels deep.

Virtual menus can be called upon at any time by way of issuing a simple voice command, for example, 'MENU CHOICES'. The application responds by reading to the user the top-level of available choices in context with the current position of the abstract pointer or an ongoing task. The interaction between the user and the interface takes the form of a conversation, albeit within a prescribed and restricted vocabulary.

Sound feedback is to blind users what a graphical display is to sighted users. The Dawn Explorer interface has been designed with this important point in mind. Every component of the interface can be associated with an arbitrary sound of the user's liking. Similar components can be associated by the same sound effect, but are differentiated by different name tags. These name tags may be read to the user on request. An important aspect of designing a user interface based solely on sound is noise clutter and this has been successfully achieved in the Dawn Explorer interface. For example, sound effects are short and are played only while the abstract pointer is in the neighbourhood of the component. The sound effect output is suspended should the pointer quickly move from the current component to the next. The abstract pointer is also required to be in contact with a given component for a minimum amount of time, before the respective sound effect is played. This is to avoid noise clutter when the abstract pointer is moving quickly across the interface and several components.

4.2.4. Auditory Interaction

In recent years speech recognition technology has improved to a level where commercial deployment of speech applications is becoming ever more common. Speech input capabilities can provide an efficient means of conveying complex commands to the computer where a similarly complex response is converted to speech output. Much work has been devoted to the establishment of large speech corpora for training, testing and system development purposes. This effort was mainly initiated by the U.S. Defence Advanced Research Agency (DARPA) and has led to much known corpora such as TIMIT, ATIS, RM and WSJ. Many of these corpora are available in the public domain, thus further encouraging research and progress in this field (Kaufmann, 1990; Garofolo *et al*., 1993; Fisher, Doddington & Goudie-Marshall, 1986; Lamel, Kassel & Seneff, 1986; Price, Fisher, Bernstein & Pallett, 1988; Paul & Baker, 1992; Kaufmann & Price, 1990).

Dawn Explorer utilizes speech recognition and synthesis technologies, for example, to navigate nested menu structures and to provide informative and meaningful feedback. The system is based on the publicly available Microsoft Speech SDK 5.1, building on speech technologies already integrated into the

Windows XP operating system and further simplifying the development process and increasing accessibility to this technology at no extra cost.

Sound effects are used to provide a spatial representation of the interface and its components. Abstract pointer movements, for example, are accompanied by a ticking noise, which changes in frequency as the pointer moves over various interface components, such as icons or different windows. Similarly, the spatial constraints of the interface are enforced when the user is made aware of having reached the limits of the interface by a sound representing a stone hitting a glass window.

4.3. Future Work

4.3.1. Abstract Pointer Control

In addition to being able to interface with traditional input devices, the Dawn Explorer framework should be able to interact with third party assistive technologies specifically designed for users with a disability.

For users with blindness or visual impairment, the use of traditional input methods, such as keyboards or mice, is not the best option. One possible solution is the manipulation of interface components by tracking movements of specific body parts of the user. Several technologies, such as computer vision, virtual reality (VR), and augmented reality (AR), make extensive use of motion tracking to acquire information regarding orientation and position of real objects.

In order to automate the human-computer interface and eliminate the need for special markers placed on the user's head, it is desirable to use the pose of the head as an additional input modality for controlling the abstract pointer. Through the addition of face recognition algorithms, the application can be further enhanced by automatically adjusting to the preferences of individual users.

For the Dawn Explorer interface one CCD camera, such as a readily available web camera, will be used to track human head movements. The optical tracking system will be self calibrating (skin colour recognition) and search for facial features once skin regions have been detected. Having recognized certain facial features, such as the eyes and the nose, the system will track these and estimate head movements and pose in 3D space. These will then be translated to movements of the abstract pointer as well as other interactions with the interface.

4.3.2. Abstract Pointer Localization

The use of tactile and/or Braille displays in addition to auditory feedback will give users with multiple disabilities, for example blind and deaf, the ability to access computer systems.

4.3.3. Virtual Interface

The graphical display will be completely removed (except for development purposes). The interface, including windows, icons and other components, as well as actions and events, will be presented to the user in an auditory format. This communication will be in the form of sound effects combined with speech synthesis to provide a spatial and dynamic interface representation. Sound effects will be easily distinguishable and intuitively associated with the different parts of the interface. Ultimately, the application framework will facilitate a dynamic interface layout controlled by the user and not in any way restricted by system.

4.3.4. Auditory Interaction

Future improvements in speech engine technologies may permit more natural conversations with a more varied set of commands and/or sentence structure.

5. CONCLUSION

In a testing environment the interface has proven itself to be easy to learn and use and intuitive in its approach to task initiation and completion as well as user interaction techniques. The multimodal design architecture ensures that the interface functionality can be extended in the future to address the needs of users with various disabilities as well as situations in which users without a disability may need to interact with a computer, for example, a surgeon or technician needing to query the computer while the hands are occupied with a different task.

Within the Dawn Explorer interface some challenges still remain. While speech recognition technology is at a high level and recognition rates of above 95% are common, the human-computer interaction cannot be compared to a human-human conversation. Some patience on the part of the user will be necessary when recognition of certain words presents a problem and warrants some repetition. However, the implementation of a training component for the speech engine will help to limit recognition failures and allow for adaptation to individual users over a period of time. Also, careful implementation of the motion tracking component of the Dawn Explorer interface is necessary to ensure that unexpected movements are not erroneously translated into actions leading to the loss of data or other unwanted actions. For example, a simple sneeze followed by an abrupt head movement should not have any adverse effects! The motion tracking algorithm will have to assess each movement and decide to act or ignore it, depending on its validity. Machine learning techniques will be used to adapt the system to the behaviours of individual users.

While design decisions were made in consultation with blind people, to this day only preliminary usability studies involving sighted users have been conducted. Testing with a blind user group is planned in the coming months.

Natural sounding speech will also be a challenge met in future versions of the application. In natural sounding speech synthesis, it is essential to control rhythm tempo, stress, intonation and accent. Many quantitative analyses have been carried out on prosody control. More specifically, segmental duration modelling and quantitative analysis have been performed on many languages using massive annotated speech corpora (Carlson & Granström, 1996; Bartkova & Sorin, 1987; Klatt, 1987; Umeda, 1975). Work to assess different approaches to prosody control is currently being undertaken and a future version of Dawn Explorer will incorporate the most suitable solution.

At this stage of the project we have already completed a functional application, which validates the Dawn Explorer framework and allows a blind user to navigate the file system on a standard computer. The Dawn Explorer application is available, free of charge, upon request by email to the authors. Thanks to its modular design the Dawn Explorer application will receive additional features that will allow users with multiple disabilities to access its functionality. The user interface presented in this paper provides significant potential for social impact as a result of the successful implementation of the Dawn Explorer application. This positive effect may be compounded by subsequent extensions to include users with different disabilities. The prospect for this technology bringing enjoyment of modern technologies to millions of users with disabilities is exciting.

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