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Assistive Computer Interface for Visually Impaired Persons

Stanislav Simeonov[1], *Dimitar Karastoyanov*[2]

[1] *Burgas Free University, 8000 Burgas*
[2] *Cenral Laboratory of Mechatronics and Instrumentation, 1113 Sofia*

1. Introduction

This field of scientific research is new in the republic of Bulgaria. The reasons are closely related to the lack of financial resources for securing basic needs of the visually impaired people. Unfortunately, little has been done for their social adaptation. The use of computer based technology certainly facilitates impaired people in their successfulness but the efforts in this direction are still insufficient. In this respect, the joint project of the foundation “Horizons” and the Bulgarian association of computer linguistics SpeechLab, together with their partners – the Union of the Blind in Bulgaria and foundation “Louis Braille”. The system was developed with donation from Microsoft. Until now, about 550 licenses were delivered, 30 of them for public organizations and community centers. It is generally considered that about 1500 visually impaired people use systems to work with computers.

Today, a tendency of increasing number of the visually impaired people working with computers can be observed. Involving blind people into IT technology is general practice in the European Union but in Bulgaria this process is just beginning. At present, there is only one visually impaired student on “Informatics and computer sciences” and she is participating in the present project. The possibilities for work in the IT sector are wide – from programming and setting computer and communication equipment to work with clients in Call centers.

The research and development in the field of assistive interfaces facilitating visually impaired people in their interaction with computers is still insufficient. The provision of a voice channel is only part of the solution. Besides, the development of interfaces often implies multiplication to larger human strata. Some statistical data: according to the Union of Blind in Bulgaria, the officially registered visually impaired people are about 70 000. However, this number is indicative since only people with 10% impairment are registered (A Step toward the Light 2007). With these data, it can be concluded that the multiplicity of the present project is guaranteed and the social contributions to the socialization of the people categorized into this group are quite more precisely defined and they are also guaranteed. Obviously, the use of computers and computer programs in modern society provides technological advantages. After 1980, computers and programs were based mainly on text interfaces. These interfaces were not a big obstacle for people with disabilities [17]. The introduction of graphical interfaces provoked the development of numerous programs using them [15]. Unfortunately, the coming and rapid development of graphical interfaces posed serious problems for visually impaired people [3]. The graphical interfaces based on visual representation and direct manipulation of objects made the adequate use of computers quite difficult for people with reduced sight. Since 1990 the migration from text based to graphical interfaces costs the jobs of many visually impaired employees [17]. Actually, the investment in ventures allowing and stimulating the effective access of visually impaired people to computers turned out to be very promising.

2. Actuality of the problem

Within the European Union, the problem with the access of blind people to computer resources is quite pressing. Studies on European and world scale are carried out in four directions.

a. A basic direction is the attempt for social integration of the visually impaired. Significant efforts are made in Germany. The main centers are two – Karlsruhe and Dresden. In 1987, Center for social adaptation of blind students was founded at the Technical University of Karlsruhe. Within this Center, optimal conditions for assisting and integration of such students into the seminar groups were provided. Since 2000, visually impaired students are tought in Informatics, Computer sciences and Computer systems. After 2007, students of other technical courses are also involved and even education in Architecture is planned;

b. Development of Braille terminals and printers and adaptation to computer systems. Braille terminals and printers are produced by leading European and world companies in various sizes. The impediment here is the fact that there is no unified system for representation of graphical and mathematical elements (e.g. integral, square root, etc.). Braille terminals, however, are not widely used due to their high price and they are suitable only where there are mainly text interfaces – philology, judicial sciences, economics.;

c. Since the communication man-computer was quite simple (mainly based on text instructions), solution of the problem was sought on the basis of voice synthesis or other forms of feedback [8-11, 16, 18-23]. These techniques have been developed before the graphical interfaces but they provide possibilities to form simple feedback to the user as voice commands. The existence of graphical interfaces and their establishment as standard for the users made the interaction of visually impaired with computers very difficult.;

d. Development of haptic interfaces based on electrically addressable and deforming polymer layer. Practically, the efforts are aimed at the manufacturing of a haptic dynamic input-output device allowing visually impaired people to obtain video information in other form. Only one research project has been announced in this direction. Technologically, the haptic devices provide great possibilities but the production of such terminal devices appears to be quite expensive at present. There are many problems with the 2D haptic representation of more complex geometrics models like images and space maps [13]. Generally, the haptic devices can apply force vector only at a single point of human body. Nevertheless, man can perceive several simultaneous touches at different points of the body. Thus, the total perception drastically decreases with haptic systems since the haptic investigation is contiguous and slow process [13]. This is especially true when important perceptions for shape and texture are not well presented or omitted at all due to technological limitations [12].

3. Prerequisites for the development of special interfaces for the unsighted

The user interface should be regarded as part of the computer system through which the user comes into physical, conceptual contact on one hand and perceptive on the other hand. In computer sciences, the interface usually describes hardware and software components allowing the user to communicate with the computer system. The style of interaction with a computational system is a basic term describing the ways the user communicates and/or interacts with it. Generally, these are menus, direct manipulation of files and natural languages. The introduction of graphical user interfaces began as early as 1980 with the so called “pseudo-graphical representation” using auxiliary elements. Since 1990 the graphical interfaces have been introduced on a large scale not only for individual programs but also as means for effective management of the operation system resources. This refers not only for the massively adopted Windows OS but also for the intelligent interfaces of UNIX and Mac-OS. The graphical interfaces a characterized by their principle of operation based on direct manipulation of objects by the user. Such interfaces directly interpret user actions (like selection, dragging, etc.) on the visual representations of the interface objects (e.g. icons), using certain input devices. This definition of a style can be generalized as WIMP (Windows, Icons, Menus, Pointers). The term is used in the context of the Graphical User Interface (GUI). These interfaces use graphical representation of elements like windows, buttons and icons. The individual graphical objects are manipulated by specialized input devices allowing intuitive actions by the user. The users carry out the actions on these objects by means of the input device. There is no unified performance style when working with WIMP. It allows certain freedom for the formation of one’s own style of working. WIMP method can easily be learned and used. Most of the applications are represented in a similar way to make it easy for the users.

From the point of view of the operation system, the interface is the highest level through which the communication man-computer is realized. The organization of the graphical operating structure of the interface, the positioning of the instructions, highlighted spaces, buttons, icons, etc. help the normally seeing users much more than before. The graphical structure of the interface is a powerful instrument. The computer mouse, as specialized input device, is the most helpful element for the use of this structure. As a result, the normally seeing people use much more often the mouse that the keyboard to do their job.

The main advantages of the mouse for the common computer users are the rapid finding and selecting objects placed geometrically above or below, to the left or right or along a diagonal on the 2-dimensional computer screen. It helps them carry out complex tasks by just using the commands copy, paste, etc, without the need to remember where exactly the real object is or what the commands for its manipulation were.

The introduction of the graphical interfaces, however, brought serious problems for the visually impaired people. The graphical interfaces based on the visual representation and direct manipulation with objects turned out to be a big obstacle for the unsighted people to effectively use computers. After 1990, the jobs of many visually impaired people were threatened with migration from textual to graphical interfaces in offices and companies. Actually, the investment in efforts the results of which will provide effective access to computers for people with reduced sight appears to be quite pertinent.

4. The concept for computer interface for visually impaired people

Despite the lack of visual contact, the people with reduced sight obtain information from the surrounding world using the other perceptions, especially touching. By touching, visually impaired people can perceive shape, size, texture, position in space, etc. This process, compared to the visual perception, is much harder, slower and ineffective but allows the unsighted good understanding of the surroundings. It has been established that each person forms his/her own mental model to sustain their reactions. This mental model comprises the operations which can be used by anyone (no matter whether they have reduced sight or not) to perceive information from the environment.

Most of the interfaces developed by visually impaired people are designed for those who had not lost their sight totally. Many interfaces use various other types of feedback like haptic and/or tactile feedback but these interfaces are usually some kind of supplement to the visual communication. There is a set of certain movements of the hand and fingers which are intuitively used by people to perceive different physical properties of the objects by touching. These movements can be grouped to form exploration procedures (Fig. 1):

- movement aside (Fig. 1a);
- pressure (Fig. 1b);

- static contact (Fig. 1c);
- encircle and follow object contour (Fig. 1d).

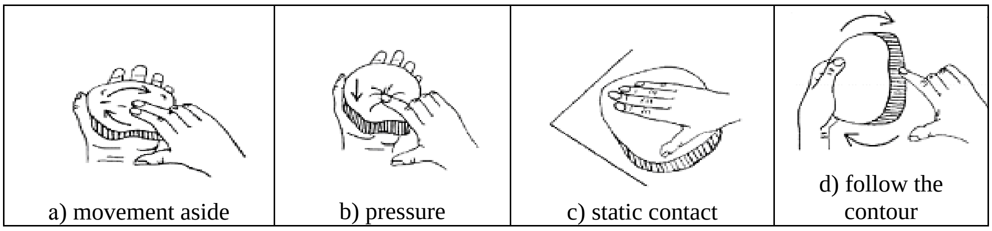

Fig. 1. Exploration procedures

The people with reduced or no sight use these model in a similar way. An important component of the ability to create cognitive models for objects in the physical world is closely related to the sense of touching. This is the only sense allowing simultaneous input/output interaction in both directions. The usual interfaces use only one direction when interacting with the user (Fig. 2a) while the tactile-voice interface can well utilize the two-way communication, thux increasing the amount of information exchanged between the interface and the user (Fig. 2b).

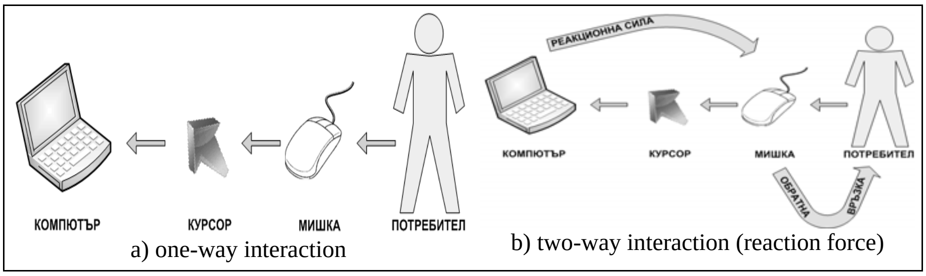

Fig. 2. Types of interaction

Obviously, many of the advantages of WIMP can not be used for visually impaired people. The researchers and designers look for a solution of the problem with the use of WIMP on the basis of a feedback using voice synthesis or other methods of passing information to the user. Such kind of techniques, developed long before the graphical interfaces, provides possibilities to create a simplified feedback to the users in the form of voice commands. However, this process is considered to be inadequate, since the exact localization of an object is concerned. Unlike common interactive devices like mice, keyboards and joysticks, the tactile-voice device would be able to function both as input devices (providing cursor location in space) and output devices (transferring additional audio information to the user). This function allows the user to simultaneously receive information and interact with the application. Working with the graphical surface, the feedback comes after the event has occurred.

The preliminary experiments with the use of feedback interfaces by visually impaired people showed that the coefficient of errors decreased and their efficiency increased. These results clearly indicate that when the user has reduced sight to a certain extent, the effectiveness of the interface can be improved by involving other perceptions.

The following example is presented to clarify the problem. When an unsighted user works with spreadsheets in MS Excel without Braille terminal, he would work mainly with the keyboard. Even with a voice feedback, the keyboard does not provide possibilities to perform all the necessary actions, such as selection of multiple non-contiguous ranges of cells in the working sheet. A simple voice feedback between the user and the graphical interface provides information on the event after it has occurred, as a result of the action carried out. Within the operation system, the information on the event is available at the moment of the request, i.e. before the occurrence. If the request could be refined on the basis of information, which compensates for the visual effect, the unsighted user would be able to carry out properly the desired action.

5. Refining the scientific tasks

The discussion above is the background for the realization of an interdisciplinary study in the field of formal description, development, design of a specialized tactile-voice computer interface for visually impaired people. The combination of two technologies – voice and tactile, will be very favorable for the visually impaired people. In this respect, it should be mentioned that there are still no specialized computer interfaces for totally sightless users. Therefore, the main scientific task can be formulated as follows: development of a specialized interface for users with any degree of sight loss. It will be based in instrumentation and methodology developed for people with full or partial loss of sight using a combination between tactile and voice technologies.

The more specific definition of the tasks for the study are derived directly from the aims stated above. The tasks can be formulated as follows:

A. Formal description of the functionality of the specialized interface

Taking into account the fact that the functionality of the interface to be developed depends on the wide range of users which will take advantage of it, it is necessary to analyze the different groups of users. In this respect, adequate formal description of the functions destined for the different groups should be created. It should be mentioned here that the interface must offer as wide range of opportunities as possible, despite social and national differences of the potential users.;

B. Design of functional computer interface for unsighted people

The formal description of the specialized interface will allow the formulation of a set of commands which will form the guidelines for the further schematic programming. In this case, it does not mean the functional design of the interface man-computer only. Substantial attention should be paid to the design of an intermediate programming layer which will play the role of instruction decoder between the specialized device and the software of the operation system. In this respect, the intermediate layer will be decisive for the functional realization of the interface. The interface discussed so far must be very carefully programmed to be independent on the operation system used. On the other hand, it should be built of modules to guarantee the scalability of the system. Besides, the differences in the maintenance of different types of software should also be taken into account. Software maintenance must be formalized at event level, at the moment when they are requested. Such an approach will provide conditions to correct user actions resulting from distracted attention, for instance. The feedback will be realized at the level of events generated by the user application to the operation system.;

C. Hardware design of the interface

The hardware design follows naturally the tasks stated above. It is intended to design an active autonomous device controlled independently of the operation system. Actually, the autonomous device is based on personal computer architecture and real-time operation system. In this respect, experiments will be carried out with generated real-time operation systems based either on UNIX or Windows technologies. The independency of the device designed a prerequisite for the realization of the formalized functions regardless of the type of operation system mounted on user's computer. Practically, communication will be realized between the autonomous device – specialized interface for visually impaired people and the computer of the unsighted user. The device envisaged will have special keyboard with additional functionality, convenient for visually impaired people. The keyboard will provide possibilities for tactile communication (Fig. 3).

Fig. 3. Tactile keyboard

It will be local to the autonomous device and will functionally compensate for the computer mouse. The device will provide a voice feedback to supply information to the user for the events which are about to happen as a results from user's actions.

So far as the modeling of human speech is concerned, it could be formed by separate components combined in a common system. For this purpose, it is necessary to model a vocal tract which will be the basis for the design of the voice synthesizer. Formal modeling could be realized through a model of the oral cavity from the larynx to the lips. To realize a comparatively adequate model, a certain number of parameters must be introduced to form an articulate vector and define the personal characteristics of each individual. The model of the human vocal tract basically consists of three components:

- oral cavity;
- glottal functional apparatus;
- acoustic impedance at the lips.

Generally, the oral cavity is modeled as an acoustic tube with slowly changing (in time and space) cross-section $A(x)$ where the acoustic waves propagate unidirectionally. Under these conditions, the following equations are suggested to calculate the pressure $p(x, t)$ and volume velocity $u(x, t)$:

$$-\frac{\partial p}{\partial x} = \frac{\rho}{A(x,t)}\frac{\partial u}{\partial t}, \tag{1}$$

$$-\frac{\partial u}{\partial x} = \frac{A(x,t)}{\rho c^2}\frac{\partial p}{\partial t}. \tag{2}$$

Differentiating (1) and (2) with respect to time and space and eliminating the mixed partials, the equation of Webster is obtained:

$$\frac{\partial^2 p}{\partial x^2} + \frac{1}{A(x,t)}\frac{\partial p}{\partial x}\frac{\partial A}{\partial x} = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}. \tag{3}$$

The eigenvalues of equation (3) are the frequencies of the formants. Solving equation (3), it is possible to find a stable sinusoidal transfer function for the acoustic tube, including thermal and viscous effects like losses along tube walls. For this purpose, substituting $p(x, t) = P(x, \omega)e$ and $u(x, t) = U(x, \omega)e$, where ω is the angular frequency, and j – an imaginary unit, and introducing the terms acoustic impedance $Z(x, \omega)$ and acoustic conductivity $Y(x, \omega)$ to provide possibilities to calculate the losses in the acoustic tube, equations (1) and (2) can be transformed to obtain

$$\frac{d^2U}{dx^2} = \frac{1}{Y(x,\omega)}\frac{dU}{dx}\frac{dY}{dx} - Y(x,\omega)Z(x,\omega)U(x,\omega). \tag{4}$$

The sinusoidal transfer function of the vocal tract can be calculated by discretization of equation (4) in space and finding an approximated solution of the differential equation (4). Let us assume the denotation U_{ik} for $U(i\Delta x, k\Delta\omega)$, and allowing spatial discretization $\Delta x = L/n$, at $i = 0$ at the glottis and $i = n$ at the lips, as shown in Fig. 1. Similar to these considerations, $\Delta \omega = \Omega/N$ and let k be $0 < k < N$. Based on these initial assumptions and denotations, equation (4) is transformed into a differential equation which, after slight mathematical transformations can be written as

$$U_{i+1}^k = U_i^k\left(3 + (\Delta x)^2 Z_i^k Y_i^k - \frac{Y_{i-1}^k}{Y_i^k}\right) + U_{i-1}^k\left(\frac{Y_{i-1}^k}{Y_i^k} - 2\right). \tag{5}$$

Fig. 4 shows the general scheme of the vocal tract model.

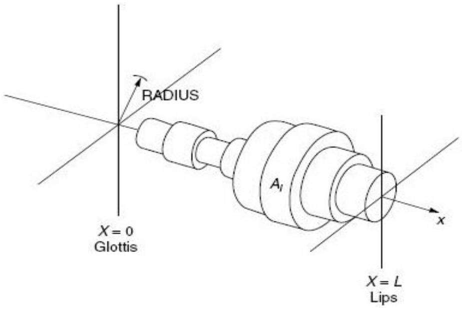

Fig. 4. Scheme of the vocal tract

The operation system of the autonomous device should guarantee its performance rate which implies modification of some of its kernel functions. According to the discussion on the job of the autonomous device, its general structure should be built in modules using as much as possible standard interfaces for communication with computer systems.;

6. Activities related to the scientific aims

The activities are determined by the scientific aims. Since the scientific study is not a standard one because it is connected with studies on functional necessity and degree of functionality of newly developed autonomous device, it comprises wide range of tasks and it is interdisciplinary by nature. The activities are described below sequentially, as described above.

D. Formal description of the specialized interface

To produce a full description, it is necessary to study the style of work of different categories of visually impaired people. The following activities are planned for this stage:

- classification of the unsighted computer users depending on their interests and profession – judicial, economic, technical, etc.;
- study of the style of work with standard interfaces – keyboard, etc., depending on the degree of sight loss;
- study the work of visually impaired people with computer systems using non-standard devices – Braille terminals, Braille keyboards, etc.;
- investigating the existing voice synthesizing software, including open source, for application in the autonomous system;
- preparation of formal description of an input flow of commands for the autonomous device on the basis of formal language;
- preparation of formal description of an output flow of information instructions for the autonomous device on the basis of formal language;
- formal description of hardware interface for the autonomous device depending on the style of work od the different categories of visually impaired people.

E. Design of a functional computer interface for visually impaired people

The designing of the functional computer interface for unsighted users depends on the fulfillment of the tasks related to the formal description. The activities are:

- choice of a hardware architecture for the autonomous device on which the specialized interface will be based. At this stage, conditions for reproducibility and simplicity should be met, aimed at lowering the production costs;
- study and classification of the application software used by visually impaired people;
- modeling the relationships between the individual software agents of different classes of application software and operation system redirector;
- classification of the relationships between the different classes of application software and different types of operation systems;
- modeling the performance of the individual agents of the classes of application software and operation systems like MS Windows;
- modeling the performance of the individual agents of the classes of application software and open source operation systems;
- defining the functions at the intermediate level of the software realizing the communication with the autonomous device;
- modeling the relationships at the intermediate level of software in operation systems of the type of MS Windows;
- modeling the relationships at the intermediate level of software in open source operation systems;
- description of an unified intermediate level for communication with the autonomous device which will be the physical interface for the visually impaired user;
- verification of the unified model on the basis of the most often used operation systems;
- development of functional diagram and scheme of the interaction between the intermediate software layer and the autonomous device;
- defining the program functions of the intermediate software layer.

F. Hardware design of the interface

The hardware designing is related to the differentiation of individual hardware and hardware-software units of the autonomous device as specialized computer interface. The device will be designed to be with as many interchangeable components as possible. The communication between the device and the computer system of the unsighted user should be based on available standardized interfaces and, if possible, without preparatory communication protocols. This will allow the possible mass production achieving the highest level of flexibility with respect to users’ degree of sight loss, interests or nationality. The following activities are planned within this stage:

- selection of a platform for the realization of the autonomous system on the basis of the architecture determined;
- study of the different kinds of communication interfaces between

input/output devices and computer systems;

- carring out of comparative analysis of the communication interfaces to select the most suitable one.;
- study the performance of the platform selected with various hardware configurations to determine the optimal platform;
- study the opportunities provided by MS Windows as a host system for the implementation in this case and determination of the reaction times observed;
- study open source operation systems to determine the reaction times;
- modeling the functions of the operation system kernels which will have to be additionally realized;
- unification of the interface with respect to the specially programmed system functions;
- comparative analysis of voice synthesizers;
- preparation of database for the realization of voice synthesis in Bulgarian language;
- realization of a voice synthesizer in Bulgarian based on open source system and testing its performance;
- defining the individual functional units necessary to manufacture working prototype of the specialized computer interface for visually impaired people;
- determination of the specific operation system and other software components which will be used in the autonomous hardware of the interface;
- functional tests of the operation system compiled in combination with the other modules;
- testing the security of the operation system against external influences.

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Вспомагательный интерфейс компьютеров для людей с увpежденным зрением

Станислав Симеонов[1], *Димитр Карастоянов*[2]

[1] *Бургаский свободный университет, 8000 Бургас*
[2] *Центральная лаборатория мехатроники и приборостроении, 1113 София*

В статье поставлена основная исследовательская цель – концептуальное построение прототипа комбинированного тактильно-голосового интерфейса, облегчающего работу людей с увpежденным зрением с компьютерами. Вспомагательный интерфейс не зависит от вида потребительского интерфейса и операционной системы компьютера, и ориентирован к граффическим поверхностям.