An Assistive Technology Computer Control System

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***Abstract*— With the advent of technology and digital inclusion, people of all social classes have been presented to the computing world. However, there is a population that, by physical limitations, has no easy and non-expensive means of interacting with a microcomputer, the motor-disabled individuals. This project presents an assistive technology system, which helps motor-disabled individuals to interact with a personal computer, consisting of a control system that captures the individual movements of the tongue and sends the signals to control the computer. A virtual keyboard, with the ability to complete words based on the user's vocabulary, is also proposed, improving even more one's experience. Experiments in real use scenarios are presented to state the feasibility of the system.**

Keywords- Assistive technology, computer control system, motor-disabled individual.

I. Introduction

Brazil has currently approximately 183.9 million inhabitants, of which 24.3 million have some form of physical or mental disability. According to the IBGE (research year 2000), 1.4 million of these people are tetraplegic [1].

Tetraplegia, also known as quadriplegia, is paralysis caused by illness or injury to a human that results in the partial or total loss of use of all their limbs and torso. The loss is usually sensory and motor, which means that both sensation and control are lost [2].

The Brazilian Law 7853 of 1989 supports the physically disable individuals ensuring the exercise of individual and social rights of persons with disabilities, citing Article 1 § 1: "In the application and interpretation of this Law shall be considered the basic values of equal treatment and opportunity, social justice, respect for human dignity, welfare, and others listed in the Constitution or justified by general principles of Law" [3]. One can consider core values of equal treatment and opportunity to be education access, information and personal independence.

With the objective of providing personal independence and digital inclusion to motor-disabled people, mainly tetraplegic, this project presents a non-invasive assistive technology system that captures, interprets and transmits signals resulting from movements of the tongue, allowing the interaction of users with a computer.

Besides the assistive technology system, a virtual keyboard, with the ability to complete words based on the user's vocabulary, is also proposed.

This article not only describes the specification and development of the assistive technology system and the virtual keyboard, but also presents experiment results obtained when using the system. It is divided as follows, some of the most relevant related work is presented in section II, the specification and development of the system is showed in section III, section IV brings the experimentation and validation results, and finally section V concludes the work.

II. Related Work

This section presents similar works whose objective is to help impaired individuals to obtain a certain degree of liberty and improve their way of life.

In [4], the authors present an educational game with modification in controls so that disability individuals can play and enjoy the game. They proposed a new Sudoku game for people whose motion is impaired, called Sudoku Access. Their special interface allowed the control of the game either by voice or by a single switch. As in our system, their solution did not focus every disabled person, but at least it benefits a lot a small portion of that group.

In [5], the authors present a great project called the Camera Mouse System. The objective is the same as in our project, i.e., to provide computer interaction for people with severe disabilities. The system tracks the user's movements with a video camera and translates them into the movements of the mouse pointer on the screen. Body features such as the tip of the user's nose or finger can be tracked. The visual tracking algorithm is based on cropping an online template of the tracked feature from the current image frame and testing where this template correlates in the subsequent frame. The location of the highest correlation is interpreted as the new location of the feature in the subsequent frame.

The project presented in [5] and our project are very similar regarding the objective and managing the mouse in a different way to interact with the computer. However, we include the design of a virtual keyboard to allow users to type words and have a better experience, using any application provided by the underlying operating system. Besides and more important, our assistive technology hardware will be increased not only to control a computer, but also a wheelchair, a TV, and other electro-electronic utilities.

A very interesting research study was conducted in [6]. The objective was to formulate a better practice model for the application of VR (Virtual Reality) intervention for adults with intellectual and developmental disabilities (IDD). The research group participated in an 8 week VR program using GestureTek's IREX video capture technology operated by the local caregiver staff. The VR programs were found to attract full participation by the participants at moderate levels of IDD but some difficulties were found in fully engaging all individuals at severe levels of IDD. Different commercial VR systems were used and were found to be usable by health-profession students and local caregiver staff. Significant improvements in physical fitness were demonstrated by the research group.

Finally, in [7] a prototype wheelchair with legs for people with motor disabilities was proposed. The objective was to demonstrate the feasibility of a completely new approach to mobility. The authors' prototype system consisted of a chair equipped with wheels and legs, and is capable of traversing uneven terrain and circumventing obstacles. The important design considerations, the system design and analysis, and an experimental prototype of a chair were discussed. The results from the analysis and experimentation tried to show the feasibility of the proposed concept and its advantages

III. Specification and Development

The development of a system like this, capable of bringing some independence to the handicapped, is of great value to our society. By including the tetraplegic in the digital realm, the system makes them able to perform daily tasks that they were not able before, providing personal independence and digital inclusion.

With this assumption, a research was initiated to develop a comfortable, practical and aesthetically pleasing device, which is inserted in the user's mouth. According to [8], the tongue, being an organ attached to the lower face (jaw) and floor of mouth, fits better to prosthesis installed on the lingual surface of lower incisors, thus making the movements more comfortable and less tiring.

With the aid of dental professionals we have developed a model of partial prosthesis, composed of two micro-switches and a mini joystick that can be nicely accommodated in the user's jaw. The joystick moves to 4 sides (up, down, left, right) and can also be used as a mouse wheel when pressed. The two micro-switches are employed as the left and right mouse buttons. The connection between the prosthesis buttons and the controller circuit is made by wire resin, reducing the thickness of wires, allowing an individual to use the prosthetic device with his/her mouth closed. Figure 1 depicts the prosthesis being constructed.

The user communication with his/her personal computer is done in a wireless fashion, sending all motion captured to the PC through radio signals. The software in the PC captures, interprets and executes the commands sent by the users.

A. Prosthesis

Before dealing with peripherals or the software, the development of the dental prosthesis was initiated. For this, it was taken into account some features of the electronic components involved (joystick and buttons) as protection against rust, against liquids and the possibility of a user to get a shock from the components. The parameters were analyzed and the electronic components were isolated to ensure user's safety.

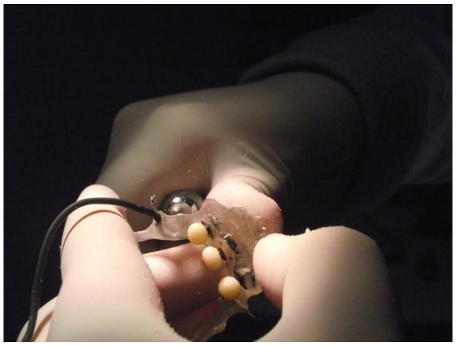

Figure 1 – Initial prosthesis model.

Since we adopted the use of a dental prosthesis, each user has to pass through a clinical phase consisting of an anatomical and physiological oral analysis. This might be considered a disadvantage since there is not a unique prosthetic device that would fit every individual. However, the construction of a dental prosthesis is costless, making the project feasible and non-expensive.

Figure 2 shows the final version of the prosthetic device. Note that the switches have been modified from earlier versions. The ones adopted in the final prosthesis showed to be more comfortable and easy to use.

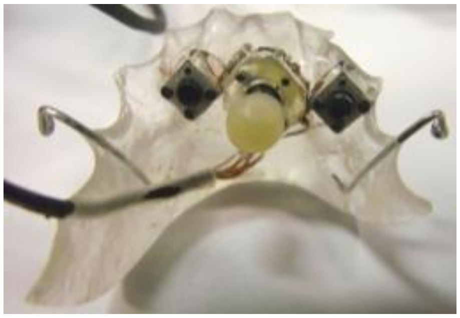

Figure 2 – Final prosthesis model.

B. Assistive Technology System – Hardware

The project designs the hardware as a set of two elements, the transmitter module, inserted in the user's mouth and specified in Figure 3, and the receiver module, connected to a PC and specified in Figure 4.

The transmitter module is responsible for the data acquisition, interpretation and transmission. The microcontroller, central core of this module, starts the variables used to capture movement and the RF (Radio Frequency) communication system. After the initialization step, the firmware in the microcontroller remains in a loop periodically checking the communication doors and obtaining new values for the Joystick, left and right switches. The serialized data is sent to the RF module, providing information to the receiver module.

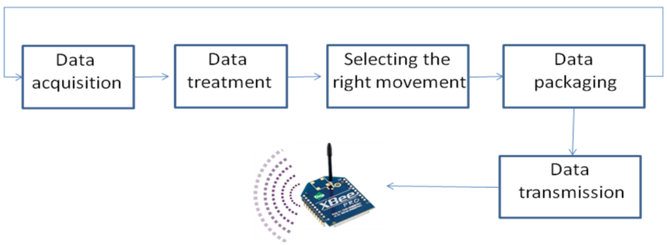

Figure 3 – Transmission module diagram.

When connected to the PC USB port, the receiver module is powered up. This module is responsible for interpreting commands from the transmitter module and encoding data using the HID Windows Class to control the mouse cursor, i.e., data sent by the user controls the mouse movement and mouse button clicks.

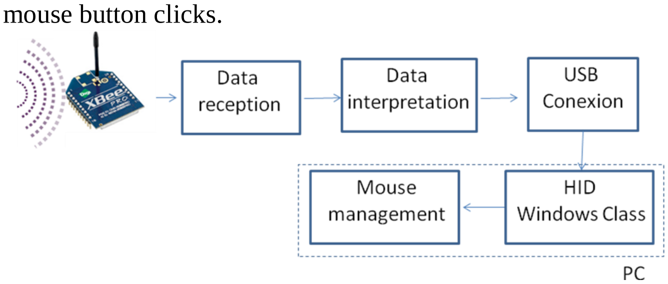

Figure 4 – Reception module diagram.

The HID Windows class is an interface for identifying human interface devices. It consists of device description classes providing information from BIOS setup and microcomputer manufacturer [9]. It allows mouse controlling without requiring the installation of additional drivers.

The commands received via radio frequency are interpreted, packaged and sent to the operating system in a vector format with four positions, each representing an operation to control the mouse, as shown in Table 1.

Table 1- Data sent to the computer in order to manage the mouse.

Vector Position	Action
0	Type of mouse click.
1	Pointer speed in the X axis.
2	Pointer speed in the Y axis.
3	Rotate the mouse wheel.

The PIC microcontroller 18F4550I was chosen because it offers the USB communication interface (necessary for connecting to the PC). Communication via radio transceiver is accomplished by the Fbee® modules in conjunction with the MiWi™ protocol stack, supporting peer to peer communication. The P2P architecture allows a decentralization of the network, thus each module can have both roles of client and server, eliminating the need for a manager or infrastructure associated with it [10].

Powered with a DC voltage of 5V each module consumes approximately 80mA CC. The transmitter module, remotely located with the user, is powered by a 9V battery. This voltage is regulated internally. The receiver module is powered by the PC USB port.

The maximum distance between the modules is given by the RF modules maximum power. In this case, the option to use the FBee transmitters has provided a maximum distance of approximately 150 meters between the transmitter and the receiver module, which in our case is much more than the necessary.

C. *Software*

With the hardware ready to use, the individual can interact with the computer by controlling the mouse. However, that was all that he/she could do. To improve the user's experience a virtual keyboard was also developed. Through this keyboard the user can type words and paste them to any application. In this fashion, one can use the Web through the interaction of our keyboard and a Web Browser, one can type words in an Editor, prepare a datasheet or presentation, ultimately one can use any application as a regular user.

Since our users control the mouse by moving their tongue, the virtual keyboard was designed to minimize the need for moving the mouse when typing. An intelligent algorithm was developed making the virtual keyboard able to complete words according to the probability of writing.

The probability calculation to complete a word is based in its incidence, making the algorithm flexible according to the user's vocabulary. To correctly complete a word, the algorithm queries the most probably word in a database. Initially, the database must be populated with a large number of words in a certain language, Portuguese in our case. Each word has a counter that accounts for its occurrence. Each time a word is used, its counter is incremented. Thus, the algorithm simply searches the word with the greatest counter beginning with the typed characters. The search only begins after the inclusion of at least two characters.

The searching algorithm returns the 50 most used words that start with the characters entered. From the feedback, the user is presented with the most probable word, i.e., the word with the highest occurrence. After selecting the word the algorithm writes it in the virtual keyboard text box. Words that have not yet been used and are not in the database might be easily inserted using the virtual keyboard.

Figure 5 depicts the virtual keyboard when a word is being typed. In this example the user wants to type "engineer", which in Portuguese is "*engenharia*". Note that after the two initially characters have been typed, the algorithm correctly completes the word automatically for the user. The user selects an application to send the word, in this case the Notepad is selected, and press a button to paste it. The application is always showed in the background.

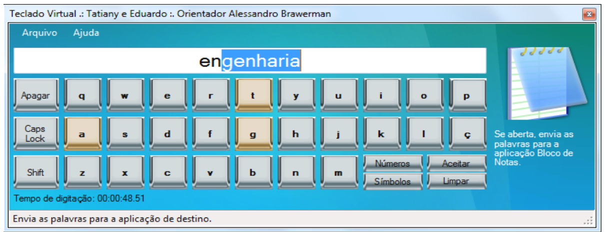

Figure 5 – Virtual keyboard model 2.

Not all possible applications are known by the virtual keyboard a priori, only the most common ones. If the user needs to interact with a new application, he/she only needs to register that application within the keyboard, which will interact with the desired application through the underlying operating system.

Because the system constantly queries the database, indexes were created on the tables in order to maintain a predefined structure to speed up searches.

A brief study on the virtual keyboard design was conducted. The idea is to minimize the need for moving the mouse when typing, hence making the user experience more comfortable. Afterwards, two interface models were projected. The first model, depicted in Figure 6, contains few buttons, and directional arrows to navigate to the next letters. The following most probably letters are emphasized in six smaller buttons located at the top of the keyboard, just below the text box. In the second model, depicted in Figure 5, the keys are arranged as in a standard keyboard with a larger size. The following most probably letters are also emphasized, but they are colored to stand out, instead of having them in special buttons.

Figure 6 – Virtual keyboard model 1.

The development of two interface models allowed a comparative study presented in the next section.

IV. Testing and Validation

This section presents results obtained by conducting experiments in real use situations. The experiments performed were testing prosthesis adaptability, virtual keyboard performance and user's safety. The testing scenario employed a laptop computer with Intel® Dual Core 1.86GHz processor, 2GB of RAM and Windows® Seven as the operating system.

A. Prosthesis adaptability and virtual keyboards performance

Every assistive technology requires some training beforehand. Our system is not different. By wearing the prosthetic device developed, the user may feel some difficulty at the beginning. With this assumption, tests were performed to assess the time it takes to learn how to use the system satisfactorily and quickly.

The tests take into account the two virtual keyboard models presented earlier and indicate which one would be better to use. To perform these tests, users were given a summary of this work for typing in both models.

To calculate the performance of our searching algorithm we analyze how many characters the algorithm needed to correctly complete the word when it was first typed. The results showed that 57.89% of the words were completed correctly with less than three typed characters and 42.11% of the words were completed with an error of gender or needed four or more typed characters. It can be concluded that for every 100 words, 58 were correctly suggested in the very first time. After that, the error rate drops to less than 10%.

Another experiment was performed to check which virtual keyboard would present the smaller route to type words, i.e., which keyboard model would require less tongue movements from our user. Using the software OdoPlus [11] to measure the distance traveled by the mouse pointer, words containing opposite characters were typed.

Considering that the mouse pointer was initially located on the center of each keyboard the characters "za" were typed. It was found that in model 1, the distance traveled was 13.14cm, while in model 2 was 8.24 cm, representing a saving of 37.19% in the route. In a second test, typing the characters “ba” the distance was 2.87 cm in model 1 and 9.76 cm in model 2, which represents 240.07% increase on the route. In general, it can be noticed that model 2 is more intuitive because it is similar to regular keyboards, which ultimately leads to a higher performance, despite the greater distance to be traveled by the mouse pointer. The results are presented in Figure 7.

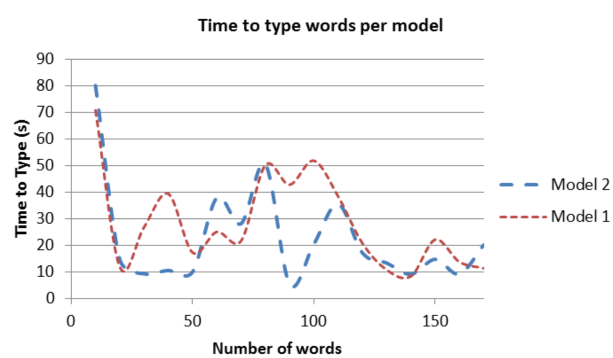

Figure 7: Time to complete words per keyboard model.

B. Algorithm adaptation and efficiency

The algorithm adaptation and efficiency experiment aims to determine the evolutionary behavior of the algorithm as the database gets populated when words are typed.

We used pieces of sections in this scientific article, for a total of 1000 words typed. Results showed that there is an increased efficiency of the suggestions in most sections entered. Table 2 shows the efficiency for every 250 words typed within text of the same subject. Considering the equation 1, which states that efficiency is equal to the saved typed characters divided by the total typed characters, the efficiency was calculated. Thus, efficiency is a rate that measures the saved characters when typing a text.

As it can be noticed, efficiency increases as the text is typed, stating that the algorithm gets used to the user's vocabulary. For instance, when typing the Hardware section, the efficiency rate was 26.60% at the beginning of the typing process, going up to 28.70% at the end of the process.

There is however some difficulty in helping to write in two situations: words of different genders, which is a problem depending on the language, like Portuguese, but not English, and differing words using their form in singular or plural. Suppose the database has stored that the words "player" occurred 10 times and "players" with 9 occurrences so far. The problem arises when one needs to write the second word. Since the singular form has occurred more times, the algorithm will keep suggesting the first word and to get the second word the user will have to type the plural form entirely.

Equation 1: Algorithm efficiency

$$efficiency = \frac{saved\_chars}{total\_chars}$$

Table 2- Efficiency of the algorithm suggestions

Theme	Beginning of typing	End of typing	Average
Abstract	4.30%	11.90%	8.10%
Introduction	16.40%	34.40%	25.40%
Hardware	26.60%	28.70%	27.65%
Results	25.30%	38.40%	31.85%

C. Reliability and prosthesis safety experiment

The reliability and prosthesis safety experiment aims to investigate the possibility of voltage existence in the prosthetic device and what, if any, is the prosthesis efficiency loss in real use conditions.

Since the prosthesis was the first piece built of this work, it could undergo a more extensive usability testing. During 10 months of use, tests were made in order to obtain an average wastage rate and loss of effectiveness rate.

The results showed that although through the naked eye the prosthesis seems totally isolated, micro-grooves allowed the infiltration of saliva into the buttons and joystick. In about nine months the prosthesis contacts did not respond. A more detailed analysis revealed that the contacts of the buttons were covered with verdigris, which resulted in loss of contact. These results allowed the observation of a definite time for loss of efficiency.

Furthermore, to improve the prosthesis quality, it was immersed in an aqueous solution simulating saliva. With the assistance of a precision multimeter, the voltage and current on the prosthesis were measured. The results were within the expected. The voltage presented in the prosthesis was 6 μV and the current was 2mA to 5mA, variation occurred with the button pressed and unpressed. The conclusion of this particular experiment is that there is no harm to our user when wearing the dental prosthetic device.

V. Conclusion

This work presented an assistive technology system composed by a set of hardware and software. The system aims to allow the user, a disabled person, mainly a tetraplegic individual, to interact with a computer managing the mouse and typing words in order to use Web Browsers, Word Processors, Datasheet Applications and any other application offered by the underlying operating system.

To allow the user to interact with the computer, the system is formed by two pieces of hardware, the transmission module, which captures the tongue movements through a dental prosthetic device, interprets them and packages this input as data to be sent. The data package is received by the receiver module, unpackaged and by using the HID Windows Class, the movements made by the user are translated in mouse movements.

Two virtual keyboards were also designed in order to let the user type words by pressing the switches in the dental prosthesis. The user types words and chose to what application he/she wants to send the data typed. An intelligent algorithm was also presented aiming to accomplish word completion. Experiments showed that after the user types three, or sometimes less, characters the algorithm was able to achieve a 57.89% correctness rate for words typed for the very first time. The rate increases as that word is repeated in our user's vocabulary, achieving more than 90% of correctness rate.

Another important experiment measured the efficiency of our completion algorithm. The efficiency is a rate that measures the saved characters when typing a text. As it was showed by the results, efficiency increases as the text is typed, stating that the algorithm gets used to the user's vocabulary. Finally, a third experiment proved that there is no harm to our user when wearing the dental prosthetic device.

Future work includes increasing our assistive technology system to not only interact with a computer, but also control a wheelchair, a TV and other electro-electronic utilities, improving even further the impaired individuals' way of life.

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