HYBRID MULTI-SOURCE, MULTI-FUNCTION PATIENT ADAPTABLE SYSTEM DESIGN FOR ASSISTIVE TECHNOLOGY CONTROL APPLICATIONS

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Abstract: This paper proposes a hybrid multi-source, multi-functional assistive system conceived with the intention of addressing the needs of a diverse group of patients with congenital, chronic, permanent or temporary motor disabilities. Differences present on patient's cases make it difficult to manufacture assistive mechanisms that can be broadly distributed. The Center for Assistive Technology (CETA) at Venezuela's Simon Bolivar University undertook the task of designing and partially developing a system that can benefit a wide variety of patients with motor and other types of disabilities. Given the design constraint, the system's primary attribute had to be its adaptability. The core of the proposed design is a configurable pseudo-real-time interface (currently in prototype stage developed under this project), limited primarily by only considering on/off signal scenarios. In order to increase the adaptability of the system and reduce the training period of the patients, changes on the bio-signals evaluation and recognition are proposed. A significant departure from the previously constructed prototype is the introduction of a FPGA board, which significantly increases the functional capacity of the system. Another important modification was considering different statistical adaptive techniques, in order to improve bio-signal recognition and therefore reducing the training period and need for calibration.

Introduction

The Human-Computer Interface (HCI) has been the centre of attention within the Assistive Technology (AT) research groups. New advances in adaptive technology and the reducing cost of some high level programmable hardware (CPLD, DSP, and FPGA) has in a way allowed the departure from HCI to a more general approach; the Human-Machine Interface (HMI or Human Device Interface, HDI). Within rehabilitation engineering, especially in the area of technological aids for disabled patients with significant motor compromise in one or more limbs, the need for HMI is becoming more evident [1]. By obtaining information from sources in which the patient still has control, (i.e. bio-signals -electromyography, electrooculography-, a limited limb movement, voice, etc.), these interfaces could be utilize for controlling/performing a wide number of functional tasks.

Motor disabilities separate an individual from their social and productive surroundings, generally causing depression and other afflictions. However, the individual maintains (in most cases) mental, oral, auditive capabilities, and even the ability of generating muscular bio-signals in some of the non-affected regions (such as the waist) or with small levels of compromise (like the neck and/or other non-affected members). EMG signals from limbs with null or little mobility, controlling a joystick or switches through the use of limbs with moderate or good mobility, eye movement through EOG, or even voice recognition (which has become commercially available at reasonably cost versions), are but some of the possible ways a disabled individual can interact with its surroundings. A wide variety of devices and actuators have been developed for expanding the capacities of a disabled individual, such devices or "assistive devices" include: mobility devices, remote controls, robotic arms [6], domestic devices (instrumented home appliances, switches, doors, etc.) and many others. These devices allow an individual to perform many functional tasks, therefore restoring some sense of self-sufficiency by allowing him/her to interact with his/hers environment and social surroundings.

In order to control these assistive devices, some kind of interface must exist. In some cases such interface is achieved without using an external device, i.e. by the use of a non-affected limb (such as using the arms and hands to control a wheelchair), but in severe cases an electronic interface is required. Depending on the patient's condition and the complexity of the task to be performed, interfaces can be either as simple as a switches, joysticks, and bio-signal (EMG) amplifier with conditioning and on/off output circuitries, or as complex as a hi-tech devices that acquire and process many EMG signals or complex joysticks for driving wheelchairs and cars, PC's, etc. An interface of the more complex kind must be able to collect some signal or information that the individual has some control over, process and condition such signal, and finally convert it into an output that the assistive device can interpret. In general we can divide such interfaces in three stages: collection/input stage, processing stage and output stage.

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The input signals (i.e. the signal or information provided by the patient) used by patients can vary greatly and are strongly dependant to the severity of the disability and the tasks that they intend to perform. Bio-signals, such as electromyography (EMG) and electrooculography (EOG) signals, head and limb movements, even voice commands, are examples of patients' input signals. On the other hand, the numbers of functions and/or tasks that the assistive devices must perform have no end.

A broad study (conducted in several rehabilitation centers, orthopedic hospitals, and augmentative communication centers, among others) revealed a lack of sufficient commercially available assistive technology devices in Venezuela's metropolitan area, especially when referring to low cost versions. It would appear that the particular details present in each patient's case make it inconvenient or to expensive for industry to manufacture low-cost assistive mechanisms that could be broadly distributed. Even for patients with the same illness, factors such as age, sex, height, weight, etc., can make it highly improbable for them to benefit from a common assistive mechanism.

The prohibitely high cost of most electronic assistive technology motivated the Center for Assistive Technology (CETA), at Venezuela's Simon Bolivar University, to undertake among their main objectives the mission of designing and developing low-cost alternative solutions within assistive technology. This paper describes the design and partial development of a hybrid multi-source, multi-functional assistive system that could benefit a wide variety of patients with motor and other types of disabilities, (see Fig 1.) and it represents an upgrade of a previous design, which has been tested [11]. Given that design constraint, the system's primary attribute had to be its adaptability.

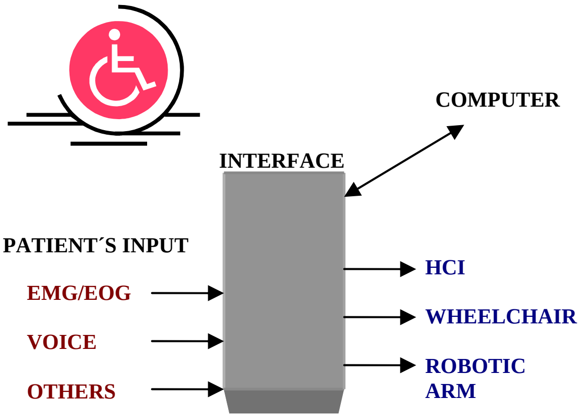

Figure 1: General overview of the proposed hybrid multi-source, multi-functional assistive system

Because of the high level of signal processing needed by the interface, this design takes advantage of FPGA technology, instead of discrete microprocessor-based approach used previously.

Materials and Methods

The system had to, above all, adapt to the patient and not the other way around, which can prove highly beneficial to patients that undergo frustratingly long rehabilitation therapy, and obviously to patients in general. Previous works done by the CETA group resulted in a low cost microprocessor based interface for assistive technology applications, designed for a patient with severe limb movement limitations due to multiple artrogriposis [11,18]. The core of that system was a programmable pseudo-real-time interface limited by only considering on/off signal scenarios. The interface was composed of: a bio-amplifier[16,19] & signal conditioning module[16,17] (8 channels for EMG and 2 channels for EOG), and ADC module, voice recognition module with speaker, RS232/USB module for computer connection, a RS232/RF module for specially designed remote actuator control, and a main processor hardware architecture based on a master-slave microcontroller scheme with an I^{2}C bus and a liquid crystal display (LCD) for system status verification. The interface was feed by a power supply based on 4 NiMH cells with an approximate duration of 18 hours. A computer interface was developed for ease of management of the input/output signals relations and overall interface control. Initial difficulties with the calibration of EMG and EOG signals threshold calibration, control by a digital potentiometer, motivated a second phase of the project.

The functional or output side experiments included the control (on/off, digital outputs) of basic electronics such as an electronic lock, a modified TV remote control, and a home-lighting system represented by an array of LEDs. A universal architecture for the interface-actuator module was devised; in such way reducing uncertainties which respect to the actuator side (see Fig. 2). The RF RS232 connection was introduced as a way of avoiding direct connection of the actuator with the patient, after which a processing stage decodes the message and activates de proper control of the specific device.

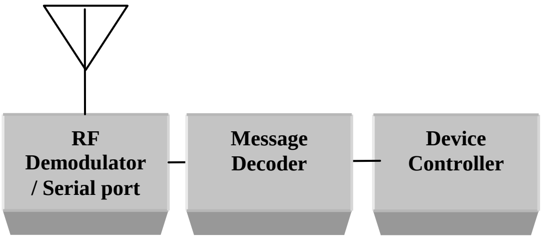

Figure 2: Universal actuator architecture

The true test was the control of a 3-dof anthropomorphic robotic actuator constructed with common motors and several general purpose micro-controllers and support electronics [8]. The robotic actuator was designed and built as a parallel project with the goal of developing assistive devices at an affordable cost. A more complete control over the

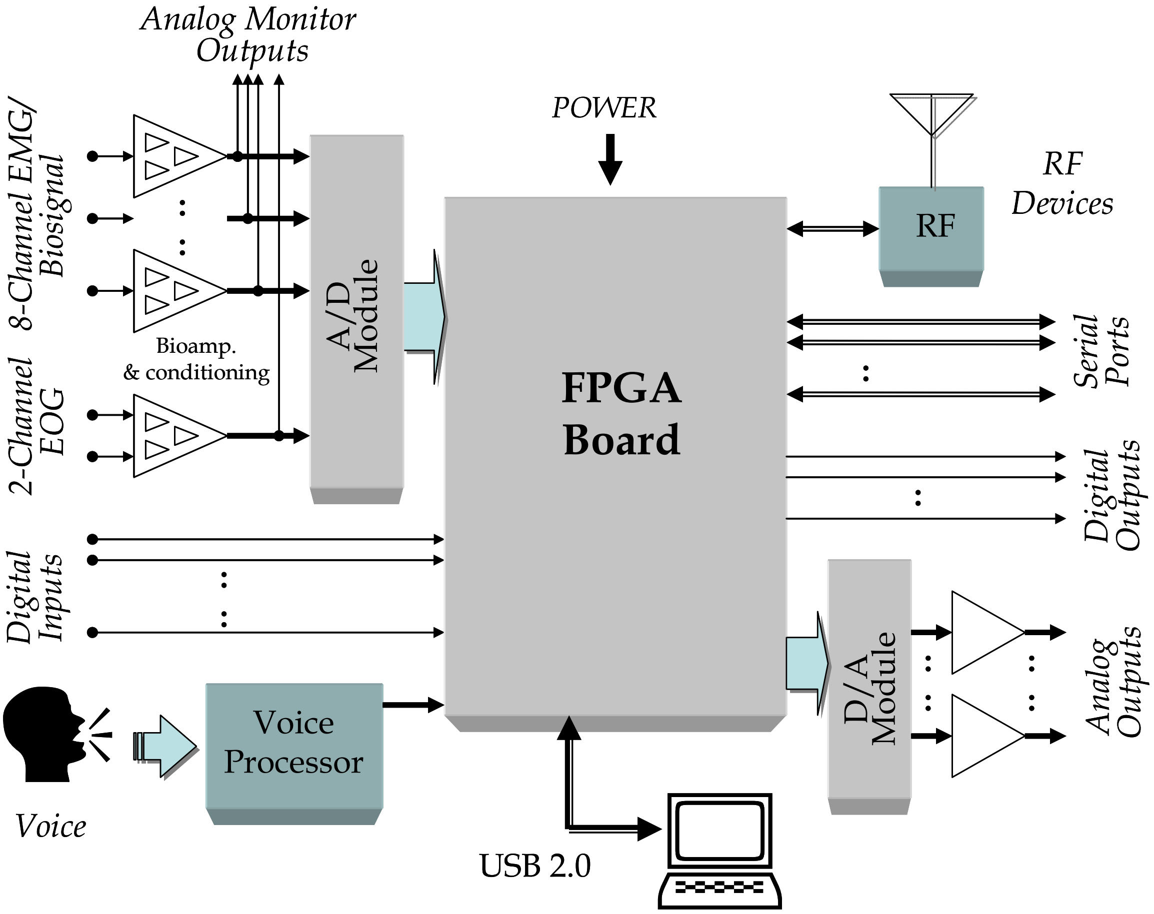

Figure 3: The new hybrid multi-source, multi-function patient adaptable system design

robotic arm as well as other complex tasks rapidly required a change in the design. Because of the poor flexibility of the microprocessor architecture, and the reduced ability to program that device with complex signal processing algorithms and control strategies, the processing stage of the interface was redesigned.

In order to improve the current circuitry of the interface, and to make it more flexible and able to implement complex processing algorithms, a FPGA board was introduced (Spartan-3 from Xilinx), which substitutes the need for several of the previous modules. Analog I/O accessory boards provide custom amplifying and filtering of the bio-signals (8 EMG and 2 EOG channels, the same signal scheme of the previous design) and I/O digital pins provide lines for entering digital signals and voice commands through a voice recognition module (Voice Extreme from Sensory Inc.), while a USB 2.0 module allows for a fast connection with peripherals or a computer, in order to control, monitor and/or program the interface. The FPGA board itself offers a number of advantages over the use of microcontrollers and purpose specific electronics. Centralizing a significant number of the functions around the FPGA board increases the robustness and contributes to the design of a custom integrated circuit based on the VHDL code used for its configuration. The software platform developed by Xilinx contributes as well by providing a solid simulation and testing environment.

In accordance to the previous design, the output stage maintains a RF module, and serial ports. In addition to the original design a series of analog output (from DAC modules) and digital outputs are considered, in order of expanding the control capabilities of the interface. A bio-signal monitor output is also included in order to allow for direct visualization/acquisition purposes.

The control of an actuator is based on the combination of one or some combination/sequence of three possible schemes: on/off action (or pulse), a specific task code, or a signal level in minimum-maximum range. This is why the outputs of this system include: digital output lines for on/off, universal serial ports and RF for coded tasks, and amplified digital-analog outputs for variable signal levels.

Such control schemes could be obtain from the subject with variables of the same nature:

- ON/OFF: from switches activated by movement or air, analog signals that exceed a certain threshold, sound, etc.
- Coded tasks: from combinations of the before mentioned, voice commands, etc.
- Signal level in minimum-maximum range: However, difficulties exist when obtaining highly controllable variable signal levels, since they must be obtained from limbs with

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mobility (which requires in most cases of a high level of training) or from bio-signals. The processing and interpretation of such bio-signals is where the advantages of this design concentrate.

Earlier works[7], within assistive technology, used EMG signals as event-type control signal based on signal amplitude evaluation (from a raw or filtered signal). An event-processing stage would then, once detected the event by means of comparison with a predetermined threshold level, associate the event with an action or action pattern to an actuator.

Recently event detection has been based on spectral indicators obtained from bio-signal through feature analysis [3]. EMG indicators are optimized when time-frequency methods are applied, such as wavelet decomposition [2,10,13], and combined with multivariable analysis, and statistical decision and classification methods [20,21]. As an example of the complexity of the calculations done in these works, see the algorithm illustrated in Fig. 4, and a resulting set of plots in Fig 5. An interface that handles EMG inputs must consider performing such level of calculations for each bio-signal channel.

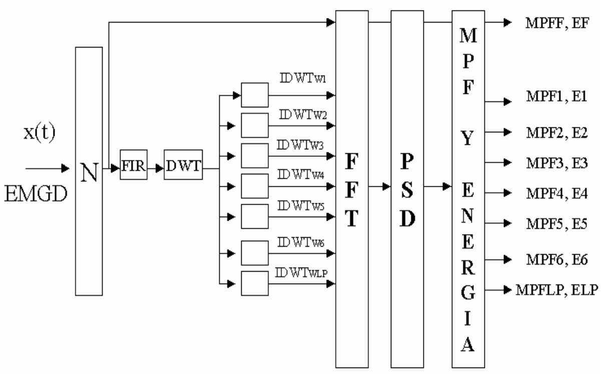

Figure 4: EMG wavelet Indicator algorithm

The algorithm starts with the raw EMG signal of a lower limb muscle, normalization (N) and a band-pass filtering (FIR) stage. Next a 7-level discrete wavelet transform (DWT)[12,15] is performed (Daubechies), followed by FFT and Power Spectral Density (PSD) of the decomposed signal is calculated; finally two indicators for all *n*-th levels are obtained using numerical integration (MPF and Energy); Mean Power Frequency (MPF*n*) and Energy (E*n*) [2,20].

For a single EMG channel, a set of 27 signals are processed by the algorithm: raw data (9 signals resulting from an EMG data plus 7 DWT decompositions and one low pass associated signal) then the FFT of the raw data, then PSD of FFT data. An example of such data set is showed as follows in Figure 5:

A limitation existed on the event processing stage, which required of powerful computational platforms in order to use the results has event handlers in real-time. Besides, such events were the product of combinational decision structures, in functions of criteria over the signal indicators.

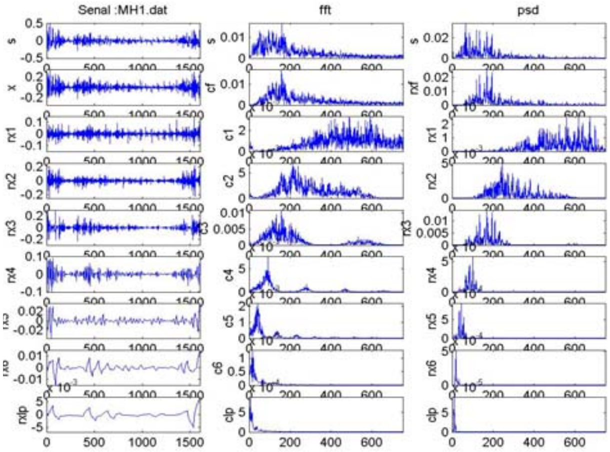

Figure 5: Example of a signal dataset used in EMG wavelet indicator algorithm.

Other methods for obtaining events in real-time from EMG propose event-processing stages based on high level structures such as neural networks [5]. Even though the use of neural networks for event processing seeks to generate responses based on training, therefore easing the adaptation process between the patient and the interface, its results while good are in general lines still distant from becoming practical (due to the large number of repetitions for the training of neural networks, which ends in patient frustration). Novel approaches are being attempted through statistical learning models based on support vector machines (SVM) [4,14], which have produced interesting results; however such approaches applied on EMG are still in an improvement stage.

Difficulties were encountered obtaining variable levels control by EMG signals due to their analytical characteristics (complex superposition of action potentials from motor units) [5,7,9]. However, it has been suggested that non-linear processing could reveal indicators of the signal (such as energy and AM/FM components), who’s magnitude could be correlated to voluntary muscular activity. On the other hand, EOG signals need no such complex algorithms, digital filtering and amplitude scaling are at most, the signal processing required.

This paper proposes to inclusion within the interface, a processing unit capable of executing complex algorithms in the event detection stage, in combination with robust statistical learning models in the event processing stage. Such event processing stage could be implemented in hardware (and therefore achieve high enough processing speeds for real-time purposes) through flexible digital machines programmed within a FPGA. This method allows for unproblematic modifications to the digital machine for processing and control of the actuators, in function of the disability of the patient.

Results and Discussion

The limitations of the original design can be overcome by the proposed modifications. A FPGA based board allows for a significant reduction of components, which contributes to a more robust design. The final structure of the interface in the phase of the project will consist in a small enclosure containing the FPGA based board, its supporting modules, and support electronics, which will process a variety of inputs (such as EMG, EOG, voice, etc.) The use of statistical learning models will reduce the training period of the patient and bio-signal digital processing will reduce the need for continuous calibration and the patient dependent factors. An arrangement of electrodes positioned in a vest will allow the patient to communicate with the interface avoiding the tedious task of placing disposable electrodes manually and the amount of cables all over the patient. The interface will then control more complex actuators such as intelligent electrical wheel-chairs, arms and other mechatronics, domestic home appliances, PC's and complex PC software applications, emergency disaster mechanism (including disaster control robots) and to improve in current Human Computer Interfacing (HCI) techniques.

Up to this point the test subjects has been limited to the professors and students involved in the project, and the control schemes implemented was the FPGA version of the previous system (digital & on/of). It is expected that in a short time we can test the system with actual patients of the various centers and hospitals we are associated with, using signal processing algorithms for bio-signal interpretation and statistical learning methods for control strategies, implemented into the FPGA.

Conclusions

There exists a need for low cost assistive technology alternatives, especially in less developed countries. Each patient needs an ad-hoc solution. This design is intended to provide an adaptable, low cost interface for disabled people who let the patient expand him/her capability to accomplish functional tasks and life expectations.

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