A Flexible, Open, Multimodal System of Computer Control Based on Infrared Light

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***Abstract*— This In this paper, a system architecture that can be adapted to an individual's motor capacity and preferences, to control a computer is presented. The system uses two different transducers based on the emission and the reflection of infrared light. These let to detect of voluntary blinks, winks, saccadic or head movements and/or sequences of them. Transducer selection and operational mode can be configured. The signal provided by the transducer is adapted, processed and sent to a computer by external hardware. The computer runs a row-column scanned switch-controlled Virtual Keyboard (VK). This sends commands to the operating system to control the computer, making possible to run any application such as a web browser, etc. The main system characteristics are flexibility and relatively low-cost hardware.**

Keywords*—Infrared System, Alternative Communication, Multimodal System, Eye, Head, Virtual Keyboard*

1. Introduction

Nowadays, there are different technologies to get signals that are used to develop interfaces. These interfaces enable people with severe motor and speech impairments to control standard computer applications. Methods to obtain signal are based on:

- Biofeedback sensors. There are several kinds of sensor that can be used: EMG (electromyogram), EOG (electro-oculography), EEG (electroencephalogram) and ECoG (electrocorticogram).
- Voice processing
- Processing images that permit gesture measurement.
- Tilt and position sensors.
- Infrared light.

Biofeedback sensors measure signals coming from body activity: electrical potential generated by muscle cells when they contract and rest can be detected by EMG sensors; eye movements cause changes in the resting potential of the retina that can be detected by EOG sensors; electrical activity of the brain can be recorded by electrodes placed on the scalp (EEG) or in the cerebral cortex (EcoG), voluntary actions can change these signals which permit control of the computer, this is the brain computer interface (BCI) basis.

If a person has the capacity to change voice articulation, voice processing techniques can be used to generate several events with the objetive of controlling the computer. Similarly, image processing can be used: different voluntary gestures generate events.

Tilt and position sensors of different technologies can be used to detect arm or head movement and this is another way of generating events.Tilt sensors or inclinometers detect the angle between a sensing axis and reference vector such as gravity or the earthś magnetic field.

Infrared light can be used in two forms: The beam generated by emitters is a pointer over a board with receiving/signal-processing modules; Receivers detect changes in the signal generated by the emitters due to human actions.

Systems based on EMG are described in [1], [16] and [17]. In [17], the system requires that the user be able to move hands and a high processing load to separate each used channel is needed. In [1], twelve channel electrodes for each hand are used to discriminate thirteen types of movements for each hand. These motions are assigned to key typing. Many electrodes and types of movement are needed. There is cross-talk between channels.

The use of EOG to design interfaces is described in ([5], [8] and [18]). In [5], the aim is to select an eye movement pattern. Once chosen, it is used to choose a picture in a communication panel used by a disabled person and his caregiver. Only an event is necessary in this application but it is a specific use software. In [8], ocular movements are translated into four actions (up, down, right and left) of the cursor in a virtual keyboard. In this system it is necessary to calculate an individual threshold, so an initial calibration is required. The subject must move his/her

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eyes as extremely as possible what causes fatigue. In [18], problems related to potential drift blinking and head movement when we register ocular movements are analysed. A calibration algorithm is proposed to solve these problems.

In [12], important components are mentioned to design Brain- Computer Interface (BCI). These are: feature extraction and classification, mode of operation, mental strategy and type of feedback. BCI interfaces require user training and the grade of accuracy depends of the subject. EEG is the most frequently used recording method, it is not invasive but it has disadvantages: poor signal-to-noise ratio, reduced spatial resolution and susceptibility to artifacts. EcoG alleviates some of these limitations but it is invasive because it requires implanting subdural electrodes. EEG can be improved using new signal- processing techniques. In [13], a VK is controlled using brain signals. classification and user training are necessary. A spelling rate of 1,99 letters/min is reached. In [11], a experimental study that shows BCI design is improved using gamma band. Elman neural network trained by the resilient back propagation algorithm is used for classification.

In [14], a complex system to recognize speech and to manipulate two layouts corresponding to a Keyboard and a mouse are presented. For users who don't have an articulate voice but can produce different sounds, it can be used scan methods manipulated by one or more event depending on user capacity.

Image processing based systems are described in ([4], [7] and [15]). In these systems, acquired signal requires complex processing algorithms, consequently real time operating is difficult. In [4] and [15] head movements are used to manipulate computers. In [7], a binary switch is activated using two tools, one of them is based on blinking and the other on eyebrow raising.

In [3], a mouse interface based on tilt sensor is designed. Users must have the ability to rotate the neck to an angle that permits reaching certain output voltages. These thresholds are necessary to avoid either oversensitivity the from the sensor or any unintended head motion as a result of which they can cause cursor movement.

An infrared based head-controlled mouse is shown in [6]. Two ways of controlling a mouse are described: absolute and relative. Head-operated mouse can use both methods, although absolute positioning requires more precise head position control and suffers from low immunity to interference. Users reported that the relative method causes less fatigue and it is easy to use. The user wears a Head Mounted unit (HMU) that communicates with a Mouse Emulation Unit (MEU). Decisions are made about system configuration. This affects the number of LEDs and photosensors and their location in HMU or MEU. The interface described in [2] has a headset that contains an infra-red and laser emitters, joined together, and an attached switch near the user's mouth. Around the PC's monitor panels with letters symbols and infra-red receivers are placed. With neck rotation, users can place laser and infra-red beams on the desired target. Then, a tongue movement over the switch selects the letter.

In [10], an infrared system is used to detect ocular movement. The idea is to get a mouse that operates in an absolute mode. This system requires calibration and algorithms that permits the correct situation of the cursor according to the point where the user is looking on the screen.

In [9], an infrared distance measuring sensor is used to design a head movement sensing system that is augmented with a voice recognition program. The user's head movement control a mouse cursor on the PC screen, the user's voice command allows performing mouse clicks and other similar operations.

The selection of one of these methods depends of multiple factors, some of them depend on the user and other on the designer. These factors are:

- User capacity to generate the action required by the method.
- Contact level (Intrusiveness) that is required by the sensors or the acquisition system.
- Fatigue caused during its use.
- System calibration requirements.
- User training process.
- Cost of the hardware that it is needed to acquire and process generated signal.
- Signal processing complexity.

The system that it is described in this work has three parts: transducers, hardware and software. The hardware is based on infrared light when these are used to detect human action (head and eye movement), the actions detected are discrete, it is pretended to generate one or more events to manipulated scanning systems. The calibration process is not desired, so the system must be based on human action that cause changes in signal that can be distinguished in an absolute way that depends as little as possible on the user. The use of infrared has advantages like: low cost, obtained signals are easy to process and the user does not require special training. In the developed system, the same hardware can be used to generate signal from ocular movements or from head movements. The software works with the events generated by processing the signal capture by the hardware. This software is open and flexible, it permits its use with signals that can be obtained by other techniques, not only infrared.

2. System Overview

The developed system has three different parts: transducers, external hardware and software.

- Transducers. The system can use three kinds of transducers; all of them are based on infrared light transmitters and receivers. Two transducers are employed to record ocular movements, the third one is for head movements. Hardware only accepts one transducer at a time, so it is not possible to combine head and ocular movement detection.
- Hardware. It generates the excitation signal to the transmitters, receives signals from receivers, filters the noise that comes from external sources (electric lamps, sun) , amplifies and modulates the signal to make an output. This output can be digitalized using different possibilities: a) sound card, b) a microprocessor integrated in hardware, or c) a data acquisition card. The sound card is a cheaper hardware solution for digitalizing. It doesn't imply additional costs because, nowadays, most computers integrate a sound card on its motherboards, and its precision is sufficient for the objectives of this work.
- Software. It is divided into three layers : 1. Acquisition layer, permits storage and signal processing to obtain primitives associated with user action; 2. Decision layer receives primitives and generates orders to the upper layer; 3. Application layer: permits input text or execute general or specific computer software.

3. Transducers

Figure 1 shows three kinds of transducers that the system can use.There are two transducers that register ocular activity. One of them permits the registration of horizontal and vertical movements (figure 1 a). This is ideal for sacadic movements or eye gaze detection. The other only permits the registration of vertical movements in both eyes (figure 1 b). This is ideal for detecting voluntary blinks and winks.

Figure 2 shows the structure of one of the ocular transducer. It is based on a glass frame into which interior bars have been screwed. Four rings are inserted on each bar; a ring contains an infrared emitting diode or a phototransistor. The diodes are placed on one of the bars and the phototransistor on the opposite bar.

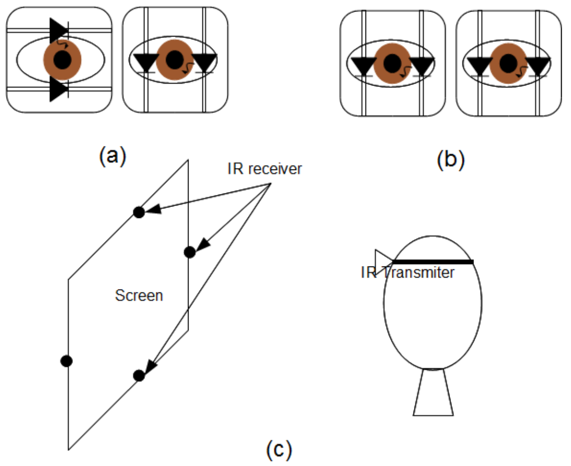

Figure 1. Kinds of transducers.

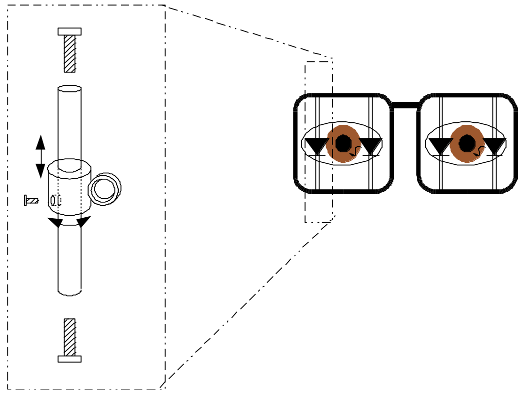
Figure 2. Diodes and phototransistor assembly in ocular transducer.

Four diodes and four phototransistors have been used in each eye. Each of them can be routed around the bar and also moved longitudinally, this means that they have two free grades and can be moved independently. This gives the system many possibilities to achieve a good fitting which is critical for optimal operation. The fitting consists of the suitable disposition of diodes and phototransistors around the eye.

Figure 1 c shows the transducer that registers head movements. This transducer consists in a head mounted unit where infrared emitters are coupled and infrared receivers that are placed on the four sides of a computer screen. The receivers measure variation on received intensity caused by the beam changes due to different head positions. Other receivers placement topologies have been analytically analysed, the best sensibility to neck rotation is obtained by the arrangement shown in figure 1. The principle of operation is the same that in ocular detection except that the excitation signal has a bigger voltage.

4. Hardware

A hardware block diagram is shown in figure 3. Transducers are plugged in the hardware device by a

DB25 connector. Headset and glass-set transducers have slightly different connector pin assignment because headset transmitters require bigger power than glass-set. In this form, eye protection is provided.

Blocks elements of figure 3 are:

- Generator. It applies a periodic square signal to infrared emitters.

- Previous stage. Photodiodes generate a signal that contains desired information modulated to 2,5KHZ and external fonts noise (mainly due to artificial light of 100 Hz). In this stage, composition and amplification of the two signal that determine channel movement is performed. In each channel four infrared photodiodes are used, output signals of each two are added, the two sums are subtracted and the difference obtained is amplified. The resulting signal has the information of the eye or head movement or position. These initial operations allow the reduction of some form of external radiation.

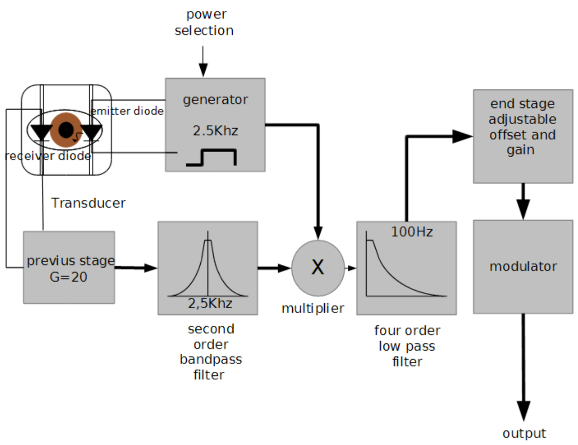

Figure 3. Hardware element block diagram.

- Bandpass filtering. It is a second order active filter tuned to 2,5 Khz.

- Multiplier and low pass filter. They extract the information (like AM demodulator).

- End stage. This stage has amplification and offset adjustment functions. It sets adequate values for microcontroller A/D converter or the modulator if the sound card is used. This stage has two outputs, one for each channel (V1 and V2) called unmodulated output in figure 3 . Figure 4 shows outputs for the transducer of figure 1a where detection of saccadic movements in the four cardinal points are desired. Figure 5 shows experimental values obtained with the transducer of the figure 1b where blink sequences detection is searched. To finish, figure 6 shows outputs of the head movements transducer of figure 1c. The sample rate of figures 4, 5 and 6 is 100 samples per second.

- Modulator. Most sound cards have high pass filter in their inputs, so unmodulated output of figure 3 have to be modulated. This stage adapts analogical signals to make its acquisition possible by a sound card.

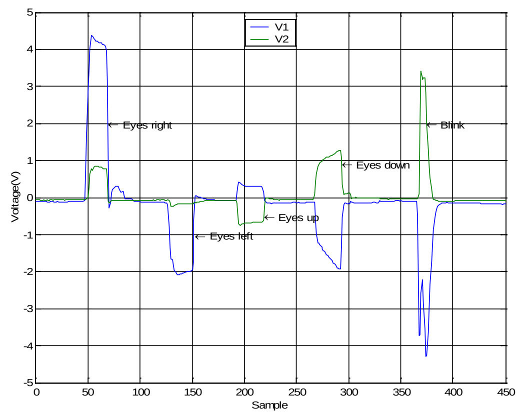

Figure 4. Saccadic sequences register controlled by a final blink.

Transducer of figure 1 (a) is used. The user generates a quickly ocular movement from the resting position to one of the four cardinal points and then comes back to a resting position. It can be observed that vertical ocular movement produces a bigger influence on horizontal channel that horizontal ocular movement on vertical one. Blink has similar response that a down saccadic movement but its time and amplitude allows the identification and later elimination.

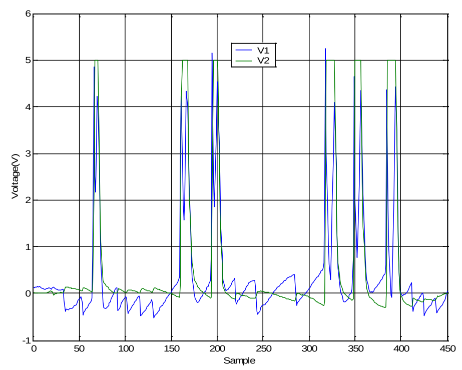

Figure 5. Forced blink sequences obtained with transducer of figure 1 b.

The user is instructed to blink once, twice and thrice with a rest time interval between blinks. During the resting time the user must read a text showed on a computer screen, with the object of determining microsaccade effects on the system.

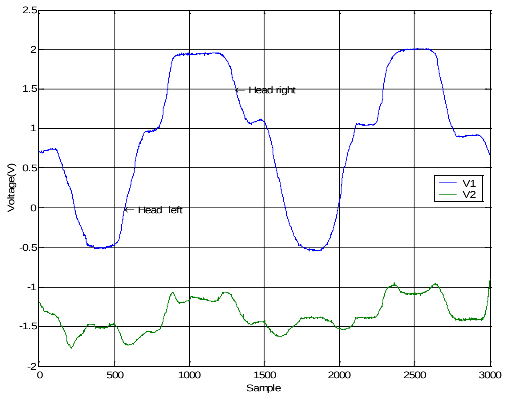

Figure 6. horizontal movement register obtained with transducer of figure 1 c.

Little influence of vertical channel can be observed. These registers have been taken from a distance between receivers and user of about 70 centimetres.

5. Software Arquitecture

Developed software is composed of three layers shown in figure 7: acquisition layer, decision layer and application layer.

5.1 Acquisition Layer

This layer is dependent on transduction type. The use of a sound card to acquire signal will be considered for explanation. This layer supplies control events obtained from the signal. It has three sublayers:

- Storage and demodulation sublayer. It is nearest the hardware. It configures the sound card and permits stereo acquisition. Buffered data are demodulated and sent to a new buffer to the next sublayer process. Demodulation can be disable or enable depending on transducer. Configuration file does it.

- Filtering sublayer. It applies a lowpass FIR filter to demodulate data of the lower layer and transfers them to upper sublayer (process). This sublayer can be disable or enable by configuration file.

- Processing sublayer. Signals supplied by lower layers are processed with the objective of obtaining information over determined primitives generated by the user: RISING_EDGE or FALLING_EDGE or a bit more sophisticated events: BLINKS, PULSE or DIRECTION for saccadic eye or head movements. All these primitives and events are designed like EVENT(type, data). Table 1 summarizes allowed types and data.

Table 1. Data and types associates with EVENT primitive.

Type	Data	Value meaning
RISING_EDGE	1,2	Channel
FALLING_EDGE	1,2	Channel
BLINK	-	
PULSE	1,2	Channel
DIREC	0,1,2,3	0:Up; 1: Right; 2:Down; 3: Left

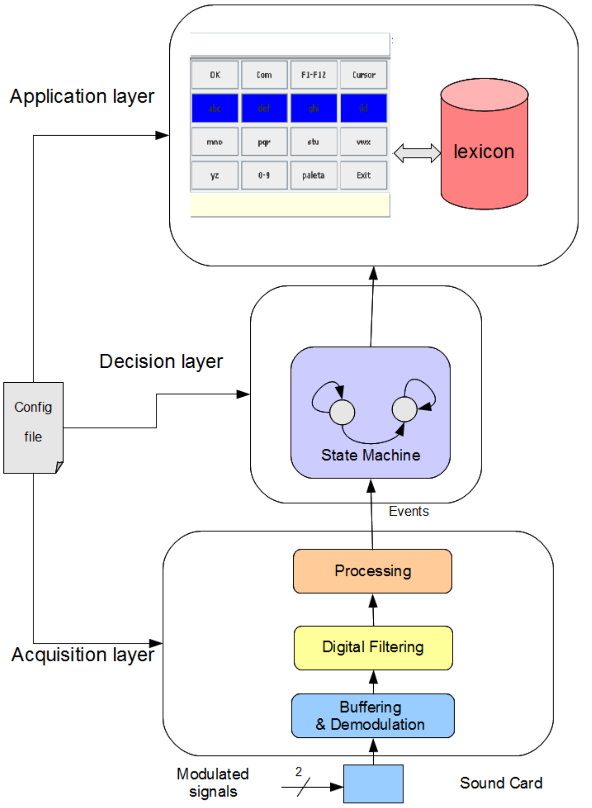

Figure 7. Software Layers.

In figure 8, the acquisition layer is illustrated step by step for blink detection:

- Storage and demodulation sublayer: It receives signal from sound card (figure 8.a), demodulates it for the upper sublayer. In figure 8(b) the original blink sequences obtained from buffering and demodulation sublayer is showed.

- Filtering sublayer: The signal is filtered (figure 8(c)) using a moving average filter. The filter's purpose is to smooth signal (it can be observed that microsaccades are eliminated by this initial filtering).

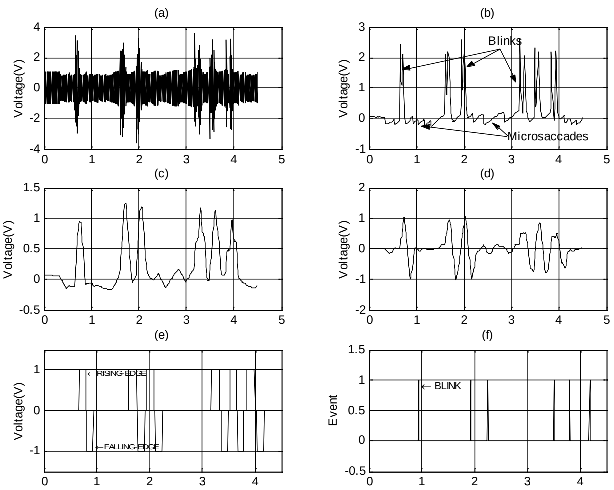

Figure 8. Blink sequences processing. For clearly only V2 channel of figure 5 is represented. In all the horizontal axis values is time in seconds.

- Processing sublayer: It does three different tasks:

- Differentiation. If a signal slopes up, its derivative is positive, else if it slopes down, its derivative is negative (figure 8(d)). Differentiating avoid successive calibration, because, although user movement can change the up and low layer values, they don't mind, only the difference between them.

- Basic events generation (figure 8(e)). Using certain thresholds stored in the configuration file RISING_EDGE and FALLING_EDGE basic events are generated. Values stored in the configuration file are obtained analysing signals from several users but can be modified. Basic primitives establish the start point to control the system by means of voluntary blinks sequences, isolated winks, combining winks, different duration winks, saccadic movements, head movements, etc.

- Secondary event generation. Using RISING_EDGE, FALLING_EDGE, and a pre-established timer (<200ms) the BLINK detection can be accomplish (figure 8(f)). Complex event generation is suitable in acquisition layer because they are frequently used and the level state machine complexity in decision layer is reduced.

Figure 9 is an example of DIREC primitive generation based on head movements of figure 6. In this figure only third and fourth steps are shown. Third step generates based events (RISING_EDGE and FALLING_EDGE). In forth step, the generation of DIREC (1) and DIREC (3) events is obtained using a state machine that receives RISING_EDGE or FALLING_EDGE base primitives during a known time interval to determine pulse direction.

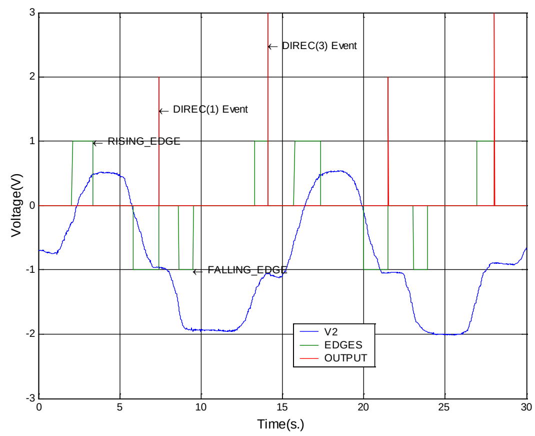

Figure 9. base an d secondary events generated by head movements.

Figure 10 shows the four secondary events generated in the fourth step based in the signal of figure 4.

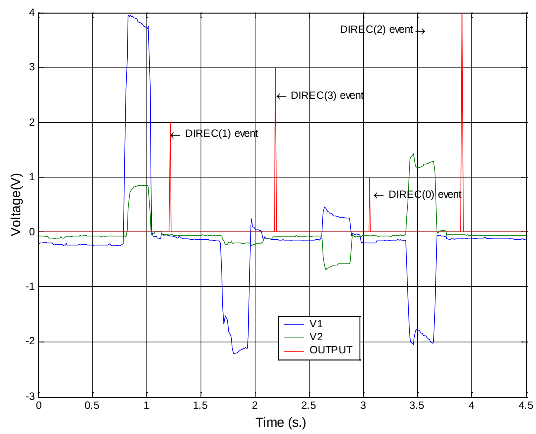

Figure 10. Secondary events generated by saccadic movements.

Acquisition layer can allow adaptation of other kind of transducer, specifically those based in a switch(on/off) mechanism. A great variety of these switches can be find in Eastin data base (retrieved from www.eastin.info). Figure 11 shows the signal capture by this layer when a switch is connected to sound card input through a pull-up resistor, these signal is used by processing sublayer to generated primary and secondary events.

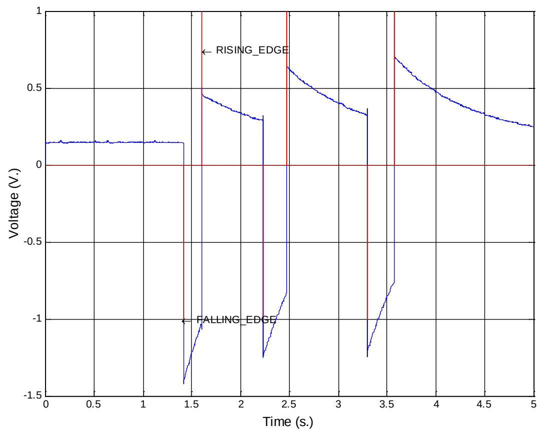

Figure 11. Signal received by sound card when the transducer is a switch. 8000 samples per second 16 bits per sample and mono.

5.2 Decision Layer

This layer executes a configurable state machine, with a limited number of timers and states. State machine inputs are events received from the lower layer (events of table 1), state machine outputs are orders sent to upper layer (Application). The output orders that we consider in our application are inputs to operative system. In this form any application that can be execute with this kind of orders can be connected to decision layer, this improves system flexibility.

Figure 12 shows examples of state machines. In figure 12 (a) a state machine that generates a selection when a wink or pulse on left channel is detected is shown. In figure 12 (b) a state machine that allows the generation of an output SEL(0) when two consecutive blinks occur in less than 1 second is shown. Two states and a timer are considered. First the machine is in State A. If a blink is received it goes to State B and a timer is activated. If the timer expires, the machine goes back to the initial state (a natural blink can be occurred). If another blink is received, output SEL(0) is generated.

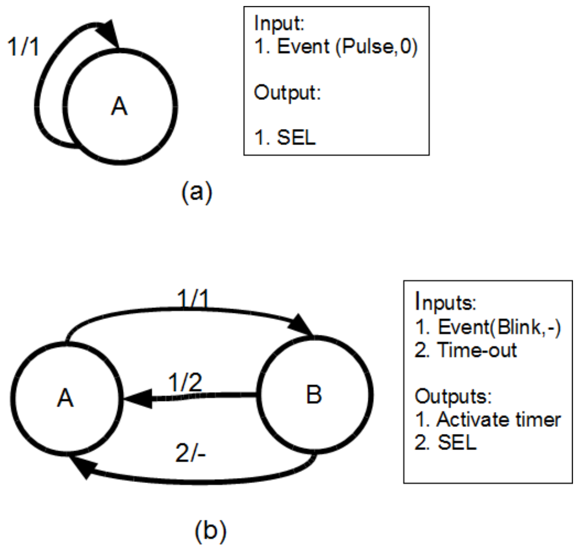

Figure 12. Configurable states machines.

In the next section a specific application develop by ourselves is described but another applications can be used with the same acquisition aand decision layers. For instance we can use a efficient text input system called dasher (it can be retrieved from http://www.inference.phy.cam.ac.uk/dasher/).

5.3 Application Layer

It contains a core that controls operative system. It is an always visible second plane application. It has grades of transparency that allows things behind it to be seen . It receives decision layer orders and it is configurable using information stored in a file. The software controls any application of an operative system by emulating key strokes without needing a mouse. This layer sends commands WM_KEYDOWN and WM_KEYUP suitable for the active program (the program containing the focus).

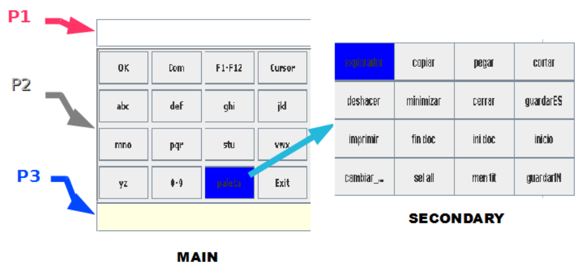

Figure 13. graphical appearance of application layer.

Figure 13 shows application layer appearance. It has two graphical tools : main and secondary. Main tool has three windows:

- P1: it contains words, sentences or command that have been built to send operating system when OK key is pressed.
- P2: it is a reduced 4x4 matricial keyboard. Each key has several options. They can be text, command or function.

- P3: It displays, in a cyclic way different options contained in the selected key.

Secondary tool is an advanced command palette. Each key can be configured to generate a command sequence. With this, frequently used programs can be easily accessed.

There are three keyboard access modes: AUTO_SCAN that generates row and column automatic scanning (user needs generate only an event); MAN_SCAN where user controls row and column scanning, the generation of two events is now necessary; and POS where selection goes forward key by key in the specified direction until the opposite is indicated (it is designed to joystick mode that it is controlled by head movements). Functional characteristics of this layer are: text writing and control system functions.

6. Experimental Results

6.1 System configured for head movement detection

A 17" screen is used for test, infrared receivers are settled in it in a quadrangular structure like it is shown in figure 1 (c). Emitters are settled in a revolving structure that allows to measure horizontal and vertical inclination with respect screen central point. This estructure is placed to different distances (d) from the screen. d changes from 60 to 100 centimetres.

Maximal angle detection for d=60cm and this screen size is enclosed between +20º and -20º. If d increase, this angle decrease gradually to +13º and -13º for d=100cm.

Parameter d determines too system sensibility(S) with the angle ($\propto$) between emitters and the imaginary line that joint them with screen center. Maximal sensibility (Smax) is obtained for ($\propto$=0º): Smax=100mV/º for d=60cm and decrease to Smax=47mV/º for d=100cm.

Other results are errors on head movement detection. For this a laser diode has been added to mark point on the screen where beam incidence is maximal. Test have been done with five users sited to 60 cm from the screen. Users are instructed to move alternatively in the four cardinal points. Laser is used to check if during the movement, infrared beam is located inside the quadrant enclosed by receivers. movement that get out from the quadrant are annotated. Altogether, a 85% of movements are inside quadrant, these movement inside the quadrant are detected correctly in a 100%. About the remaining 15%, 75% is detected correctly and only a 25% generates errors. Mentioned errors have been due to a considerable beam deviation from the quadrant.

6.2 System configured for blink and wink detection

For this test, transducer of figure 1 (a) is used. Emitters and receivers are directed to the centre of user pupil. Objectives are settled on the wall in a circular way and the user is placed to 100cm from them. It can be imagined that gaze trajectories are inside a cone which vertex is the equidistant point to user's pupils and its base is the greatest radio circle represented by objectives fixed on the wall. Maximal angle which form the cone with respect its axis is $\propto$_max=40º. Test have been done with five users with different colour iris.

User is requested to generate a voluntary sequence of three consecutive blinks when his gaze is inside mentioned cone because he is looking at any of the objective points. Obtained signal is registered and processed. Error of blink detection is increase with $\propto$. There is no error for $\propto$=20º and a 5% error for $\propto$=40º. Process for wink detection is the same and similar results are obtained.

It must be mentioned that error established for $\propto$=40º is the average value for any point of external circle but upper or lower points have grater error than horizontal points more distant.

6.3 System configured for saccadic movement detection

For this test, transducer of figure 1 (b) is used. Emitters and receivers are directed to the centre of user pupil. Objectives are settled on the wall forming a cross and the user is placed to 100cm from them. The cross centre is aligned with a equidistant point to the user´s pupils (line L). The position of each objective is calculated in order to the angle that form user gaze with line L change form 0º to 50º with a difference of 10º between each of them. 20 trials with 5 users have been carried out . In each trial, the user must generate a quick ocular movement to a objective a return to the origin. These movement must be generated after a blink to reduce interferences with voluntary movements.

For a 20º angle, the number of errors detected in sacades detection is greater than 14%. This error drops with the angle being lower than 1% for angles greater than 40º.

7. Operational Procedure

System configuration is established depending on user capacity and numbers of commands of the application software. It has been mentioned yet that application software described has three keyboard access modes. AUTOSCAN mode requires only one command, this mode is the ideal with users with very reduced mobility. States machines proposed can be used, a pulse generation would be required if we consider machine of figure 12 (a) or two blinks in less that one second if state machine of figure 12 (b) is chosen.

MAN-SCAN mode requires two commands. Depending on user capacity head or ocular movement can be chosen, one sense of movement event must be translate to one command by the decision layer, for this case timers are not necessary. If the user only can generates one event (a blink for instance), it is posible generates two commands combines the number of occurrences of this unique event and time(in this case timers are necessary), two consecutive blinks must be command 1 a three consecutive blinks command 2.

POS mode requires five commands. Again different events of table 1 can be combined using configuration state machine of decision level to generated these commands. A efficient option could be use the transducer based on eyes movement: direction events can be associate to four commands that permits translation between keys, for selection command two consecutive blinks or a wink can be used.

8. Conclusions

The tool presented has advantages in both functioning and design. In functioning it is easy to use and it does not require any training. All its possibilities are included in sixteen keys permanently shown on the computer screen. It must be mentioned that the user must have experience handling computer using control keys of a standard keyboard.

In design, it is flexible with respect to two aspects:

- Main keyboard presented on screen. An adaptation of the main keyboard has been accomplished according to different types of users permitting several configuration throughout the keyboard during execution time. For instance, different numbers of keys, or letters by key, sizer colors, etc. can be used.

- The input signal. Several transducers or devices can be used to generate this signal. In this work an infrared device has been selected but the modular system design allows devices based on other technologies to be included without many changes.

As it has been mentioned, the system allows high flexibility in selecting the kind of sensor: external switches; ocular or head movement detectors. The system is flexible too with respect to event configuration: blink sequences, saccadic or head movements or sequences of them. But an expert is required to configure and to adapt the application to each user. The expert determines decision layer state machine. However most external devices for the disabled are based in one event detection and have a relay output; or handling a potentiometer (joystick).

A hardware device that adapts these devices outputs to USB port is under development. At the same time an adequate acquisition layer has been designed to pick up mentioned hardware information and to allow interact with decision layer. A virtual mouse will be included to increase versatility.

Acknowledgments

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