Jornada de Seguimiento de Proyectos, 2005
Programa Nacional de Tecnologías Informáticas

Sistema de Apoyo a la Visión mediante una Retina Artificial Neuromórfica a través de Realidad Aumentada
TIC2003-09557

José Manuel Ferrández*
Universidad Politécnica de Cartagena

Eduardo Fernández**
Universidad Miguel Hernández

Abstract

The construction of a system for aiding some kind of blindness is proposed. It consists in a bioinspired retina model into a reconfigurable architecture which is connected to an augmented reality device based on see-through technology. This device will permit the integration of real world images to the ones obtained by the neuromorphic retina. This system will provide a local gain control, in addition of a bioinspired preprocessing, FPGAs plasticity, and the miniaturization of the components, including low power devices. These characteristics are highly desirable in some low vision supporting systems.

Keywords: Neural acquisition, retinal coding, cellular neural networks, augmented reality.

1 Project Objetives

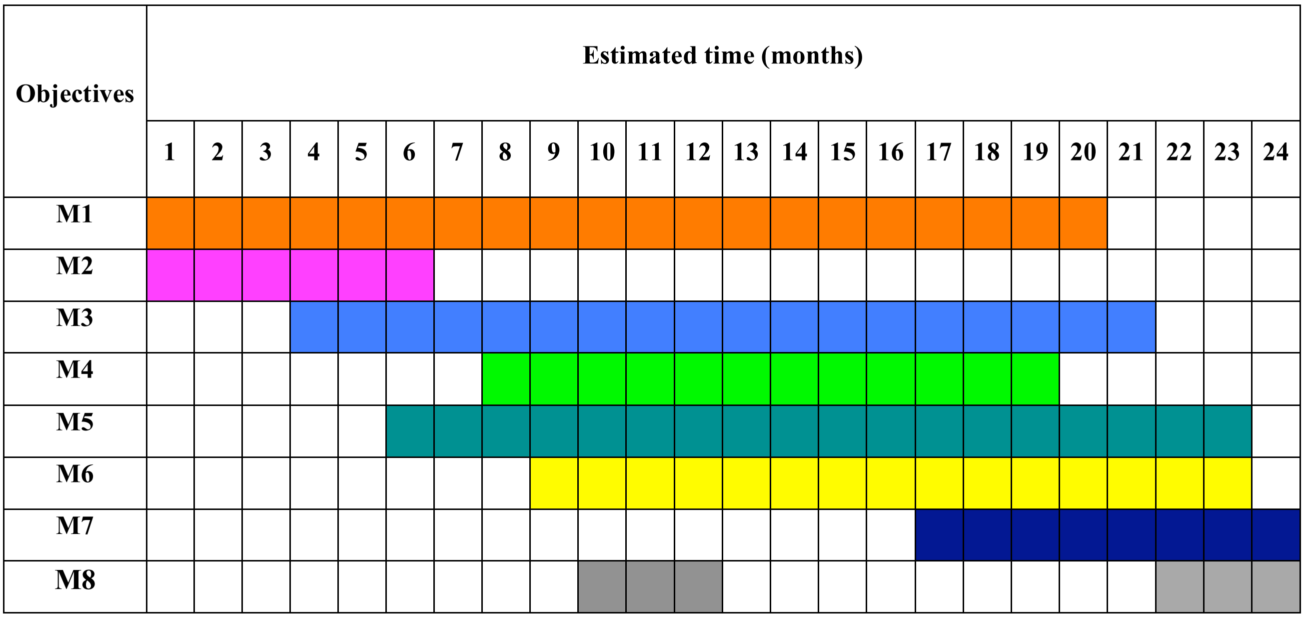
The objectives defined within the project are structured in a workplan. The list of objectives, with the estimated time and the responsible unit is the following:

- **Objective M1:** Study of the processing and coding capabilities of population of ganglions cells in the visual system.
  Estimated time: 20 months
  Responsible Unit: Universidad Miguel Hernández
- **Objective M2:** Define mathematical algorithms and simulation tools.
  Estimated time: 6 months
  Responsible Unit: Universidad Miguel Hernández
- **Objective M3:** Cellular Neural Network development
  Estimated time: 6 months
  Responsible Unit: Universidad Miguel Hernández

* Email: jm.ferrandez@upct.es
** Email: e.fernandez@umh.es

- **Objective M4:** Cellular Neural Model VHDL implementation
  Estimated time: 12 months
  Responsible Unit: Universidad Politécnica de Cartagena
- **Objective M5**: Software/hardware system partition.
  Estimated time: 18 months
  Responsible Unit: Universidad Politécnica de Cartagena
- **Objective M6:** Reconfigurable hardware design.
  Estimated time: 15 months
  Responsible Unit: Universidad Politécnica de Cartagena
- **Objective M7:** System adaptation to low vision problems. Augmented Reality application
  Estimated time: 8 months
  Responsible Unit: Universidad Politécnica de Cartagena
- **Objective M8:** Meetings, Publications and Patents
  Estimated time: 6 months
  Responsible Unit: Universidad Politécnica de Cartagena and Universidad Miguel Hernández

The described Workplan Flow Chart is



Means to achieve the objectives

The group at Universidad Politécnica de Cartagena is devoted basically to the development of the neural network models and its electronic implementation, as the augmented reality real time application. The group at Universidad Miguel Hernández is devoted to the acquisition of multielectrode recordings from retinal ganglions cells, and analizing the coding capabilities and strategies of the visual system.

The equipment used by the group at Universidad Politécnica de Cartagena is composed by Xilinx FPGA development system, a network of workstations for simulation under MATLAB ® , Sony Glasstron PLM-700 augmented reality glasses, as well as different simulation software both for WINDOWS and LINUX.
The equipment used by the group at Universidad Miguel Hernández is composed by a multielectrode recording setup which consists in a fixed workstation for amplification, data recording and storage running Cyberonics systems, a multielectrode array developed in Utah. The recordings analysis is made with WINDOWS and LINUX systems.

2 Level of success achieved

2.1 Neural acquisition and analysis
Understanding how information is coded in different sensory systems is one of the most interesting challenges in neuroscience today. Much work is focused on how various sensors encode different stimuli in order to transmit information to higher centers in the neural hierarchy in a robust and efficient manner. Technology is now available that allows one to acquire data with more accuracy both in the temporal and the spatial domains. However this process produces a huge neural database which requires new tools to extract the relevant information embedded in neural recordings. However, it allows one to postulate some rules about the way different neural systems do this coding.

The Utah microelectrode array was used for obtaining the extracellular recordings. The electrode arrays contain 100 electrodes that were built from silicon on a square grid with 400 microns pitch. The distal 50 microns of the needles, metallized with platinum, form the active site of each electrode. The array was mounted on a micromanipulator, and each electrode was connected to a 5000 gain bandpass (filtered from 250 to 7500 Hz) differential amplifier. The analog signals were digitized and stored in a computer. The pre-processing consisted of fixing a threshold (based on an estimate of the noise of the electrode) in order to extract the kinetics of electrical activity above this threshold. Spike waveform prototypes were separated by template matching. For each stimulus and for each electrode, the time of the first and second spike, the number of spikes, and the interspike interval during the flash interval was also computed. (Figure 1)

Different studies have used different analysis tools to approach the decoding objective. It has been applied a statistical analyzer to the neural data in order to estimate the characteristics of the stimulus, and also linear filters for the decoding task. Other approaches used to get insights into the coding process are discriminant analysis, principal component analysis and supervised and non-supervised neural networks. Finally information theory and synchronicity studies have been used for analysing the synergistic or redundant behaviour of the code, and for determining the relevance of the temporal and spatial parameter in the code and also to check if there exists a population code instead of an aisle cell code[1],[6]. This studies have been applied in refining the parameters of the cellular neural network.

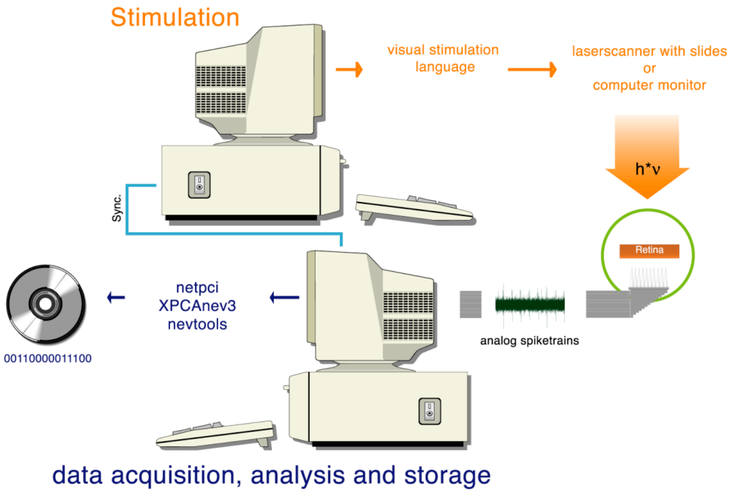


Fig 1. Recording method

2.2 Neural Tools developed

The number of laboratories using techniques that allow to acquire simultaneous recordings of as many units as possible is considerably increasing each day. However the development of tools used to analyze this multi-neuronal activity is generally lagging behind the development of the tools used to acquire this data. Moreover, the data exchange between research groups using different multielectrode acquisition systems is hindered by commercial constraints such as exclusive file structures, high priced licenses and hard policies on intellectual rights. It has been developed a free opensource software for the classification and management of neural ensemble data. The main goal is to provide a graphical user interface that links the experimental data to a basic set of routines for analysis, visualization and classification in a consistent framework. To facilitate the adaptation and extension as well as the addition of new routines, tools and algorithms for data analysis, the source code and documentation are freely available.

The main aim of this work was to provide a free open source software that allows an effective multielectrode data exchange between laboratories regardless the commercial system used for the recordings and that, at the same time, make available appropriate tools for an easy and fast pre-processing of the data [7],[8],[11],[14]. Data sharing requires agreement on techniques and formats, as well as methods for classification and selection therefore DATA-MEAns provide several visualization and analysis routines which permit to classify and reduce original datasets for further specific processing. Furthermore to facilitate the adaptation to any particular requirement as well as the addition of new routines, tools and algorithms for data analysis, the source code and documentation is freely available. We hope that it will help new contributors to add functions that are currently not included and that it could be useful for further analysis that allow integrate and compare findings from individual laboratories as well as test new hypothesis.

DATA-MEAns can read ASCII files created by popular data acquisition systems. These files can be easily created and edited using a word processor or any other program for editing text files. Although working with binary files allow to come up with more information, this approach would require huge and continuous efforts for putting together all different file formats, reading them, and updating the "read modules" since the commercial acquisition systems often upgrade their native data files. Moreover, many laboratories use home-made acquisition systems, being excluded from using most of the commercially available software. Our goal is that this toolbox can be useful to the development of standards, all in a common format, which support multiplatform assembly, upload, annotation, search and acquisition, that will ease reanalysis of shared data by permitting data upload from within data acquisition applications, and data download directly to standard acquisition routines.

The design based on stand-alone applications offers great flexibility and independence from any other commercial software and represents an easy mechanism for adding new routines altering minimally the source code. This can be particularly useful when the researcher uses their own custom scientific programs. Thus it is possible to write the desired algorithm using a known language, make an executable and link it to the DATA-MEAns application by means of the ShellApi utility from Windows. Anyway we are working on a new multiplatform version of the software that will run under MacOSX and Linux. Finally, this application was intended only for a preliminary pre-processing of the data, hence only the most generally used routines are implemented, (Figure 2). We are aware that numerous functions currently in use, as well as advanced functions used in various labs working with multi-electrode data are not included. We hope that the facilities to extend the code and add more specific algorithms and routines can compensates the former and encourages the users to contribute providing ready-made functions useful to the scientific community. Thus, the program and source code are available free of charge upon request from the first author of this paper (email: p.bonomini@umh.es) or directly from the following URL: http://cortivis.umh.es (under the software menu), to academic researches interested in using or enhancing DATA-MEAns.

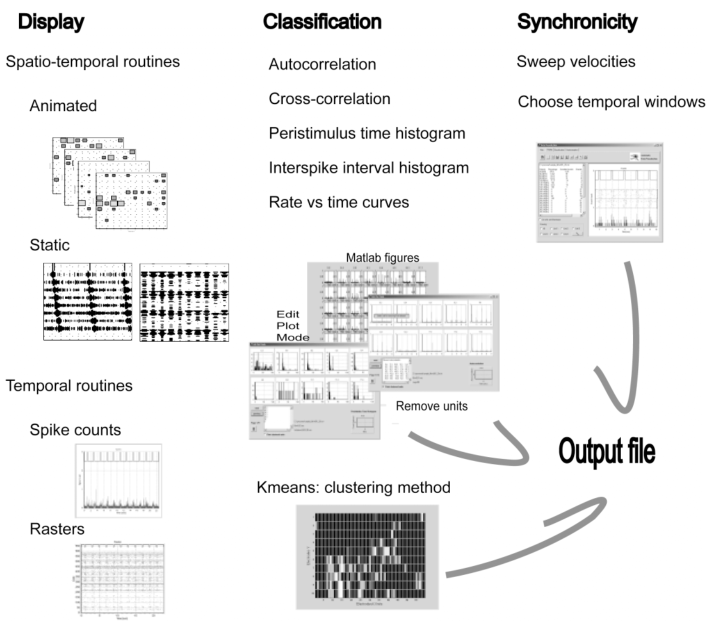


Fig 2. Functions implemented by DARA-MEAns

2.3 Model implementation

Cellular Neural networks (CNN) are a powerful analogue parallel computing paradigm. For software applications, which do not require a great capacity of processing, many practical applications have been implemented using general purpose microprocessor or DSP processor. However, for intensive computing applications such as real time signal processing, video processing or retinal emulation, a hardware implantation is necessary in order to achieve the maximum processor capacity required by these applications. In order to find the best approach in both cases, a new approach to Cellular Neural Networks model is used [16]. This approach is focused on CNN implementation on reconfigurable hardware architectures (FPGAs) and DSP microprocessors. The CNNs are analyzed from the perspective of systems theory, giving rise to an alternative model to those found in the literature available. Dynamic equations and their solutions, stability analysis and real-time implementation architecture are described as the most relevant points in the development of our model.

From the point of view of CNNs hardware implementations, local connectivity and intrinsic analogic parallel processing provided a first advantage to VLSI implementation. However nowadays, digital devices such as FPGA are playing an important role by competing with the VLSI circuits not only by its low price, but also by its features and versatility in the design. The new families of FPGA, which are emerging these last years, provide many hardware resources such as: optimized Block Select RAM, embedded multiplier accumulator (MACC), fast carry logic etc. These features and their capacity for parallel processing have increased the flexibility to map modular neural structures into FPGAs, although it is necessary to use hardware element as much as possible. That is why, we have proposed to analyze different digital models of CNN neuron [17], which arise from the original continuous model, to find the model which employs the minimum resources possible for its implementation, and is a good approximation of the continuous model as well (Figure 3). The main results, obtained from different implementations [18, 19], evidence the usefulness and functionality of the selected neuron model.

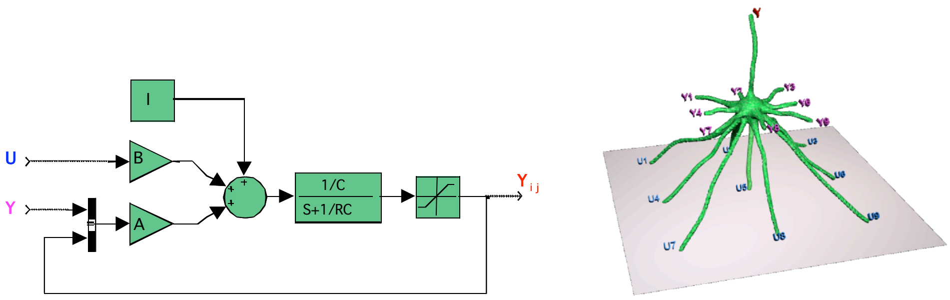
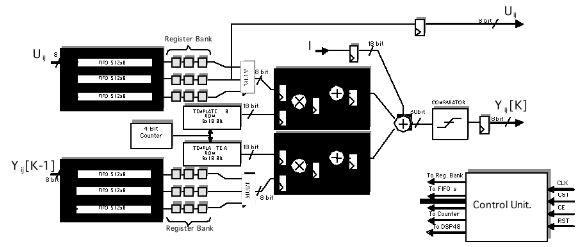


Fig. 3. Mathematical model and symbolic 3D representation of a single neuron

The most interesting result obtained with a single neuron in term of speed and area resources (Figure 4) has motivated the search of different solutions for the complete implementation of a great Cellular Neural Network with over 300.000 equivalents cloned neuron in a single FPGA. For this task we have proposed a novel architecture based on self-clocked approach which has given excellent result in other similar applications [20, 21] and that is very hopeful for the design of

CNN. Future works will focus on the design of multi layer CNNs as well as CNN with not cloned and CNN with nonlinear and variant in the time coefficients. Another aim is to connect the full neural network to co-design system [22] to achieve a greater versatility in the design and test of applications with CNN.



Resources	Units	XC4VSX35 Used (%)
Area (slice)	115	0.749
Flip flops	136	0.443
DSP48	2	1.042
BRAM	2	1.042
Global clocks	1	3.125
Max. internal freq. (Mhz)	283.28	-
Max. pixel freq. (Mhz)	17.70	-

Fig. 4. Single neuron architecture and summary of used resources

2.4 Augmented Reality application

At present, an Augmented Reality (AR) system fully based on Field Programmable Gate Array (FPGA) devices is being developed. It aims for providing patients affected by a visual disorder known as tunnel vision with a help for their loss of peripheral vision. Tunnel vision is associated to eyes diseases such as retinitis pigmentosa and glaucoma, and it reduces considerably the patient's ability to localize objects or persons and navigate, and consequently, his relationship with people and the environment. To enhance the user's knowledge of the environment, we have adopted an AR approach where information considered as useful is presented to him thanks to a see-through Head Mounted Display (HMD). This information consists of the contours detected on the images captured from a camera worn by the user. An example of the view of the user through the HMD is shown in Figure 5. It can be seen how the contour information is superimposed on the user's own view.

Fig. 5. Simulation of patient's view through the HMD looking at a clothes stand situated on a corner and beside a shelf.

In order to achieve both the constraints of size and power imposed by the mobility of the system, and the requirements of high performance of the application, an FPGA-based platform is proposed. Reconfigurable hardware offers a trade-off between the very specialized solution of Application Specific Integrated Circuits (ASICs) and the inefficiency of General Purpose Processors (GPPs), combining the desirable high performance of ASICs with the characteristics of system flexibility of GPPs. Like ASICs, it involves hardware implementation and consequently parallelism and high performance. Like GPPs, it provides reconfigurability, and hence flexibility and rapid prototyping. So, it is possible to implement not only specific algorithms but also interfaces, controllers, glue logic, even microprocessors, and so to integrate the whole system in just one chip.

To extract the contour information two different approaches have been developed, implemented and evaluated: the Canny algorithm and a cellular neural network with the appropriate template. The first one is a specifically designed solution to extract edges from images. The second one is a more versatile solution, thanks to the possibility of modifying the processing through the change of the template set. The Canny algorithm is a well known image processing algorithm for extracting contour information. We have proposed [23] a novel FPGA-based architecture for its hardware implementation, optimized for Xilinx Virtex-II devices. Specific purpose resources included in this family of FPGAs, such as embedded 18 bits multipliers and internal BlockRAMs, have been used to achieve efficient implementation. It is able to process up to 1024×768 pixels image at 60 Hz, reaching the real time execution required for the application.

Nowadays, the advantages of the combination of massive parallelism and local interaction among cells that offered the CNN are well known, especially for image processing. Moreover, in our application with the use of CNNs we aim to increase the versatility of the system, making possible to tune the output to the desired and to perform different processing algorithms just by changing the template set. For CNN hardware implementation, VLSI design has been the most suitable choice to exploit their advantages up to now. For our application, we have described CNN discrete models focused on the implementation in reconfigurable hardware [24, 25, 26].

The system is shown in Figure 6. It consists basically of a camera to acquire images of the environment, a head mounted display to visualize the information that enhances the user's vision, a Xilinx Virtex-II FPGA as processor and controller unit and SRAM memory to store information. The camera is a monochrome module with a 384×288 pixels 8 bits digital output at 50 frames per second, based on a CMOS image sensor. The HMD used is the Sony Glasstron PLM-S700E. It is a binocular and high resolution device with adjustable see-through capability. Its design and light weight allows its use with correction glasses and makes it easy the movement of the head and the mobility of the person. VGA synchronization signals for the HMD are generated by the FPGA to show a 640×480 pixels image at 60 frames per second. The SRAM memory is necessary to store image from the camera and, in the CNN-based system, information between different stages. The memory interface for controlling the write and read operations is implemented on the own FPGA. For the Canny-based approach, a XC2V1000 Xilinx FPGA has been used. The implementation results and timing statistics are shown in [23, 26]. For the CNN-based approach a XC2V4000 Xilinx FPGA has been used. Initial implementation results are presented in [24] and improved results in [25, 27]. A comparison between the two approaches is carried out in [26].

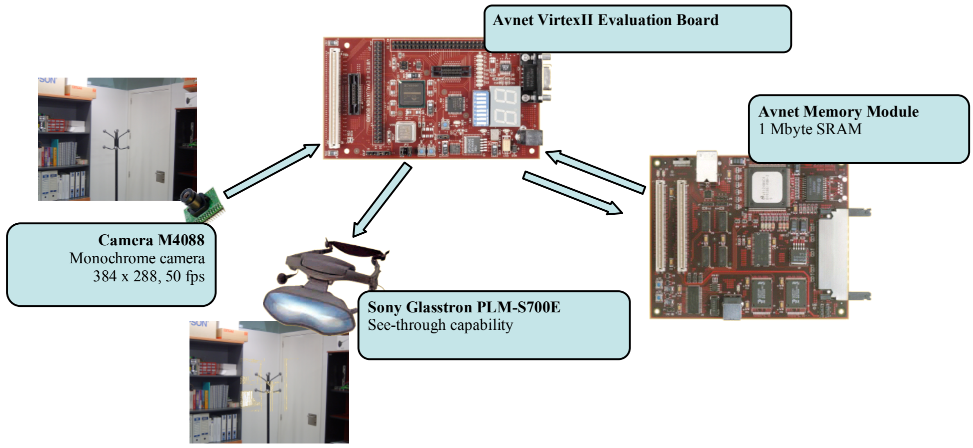


Figure 6. System Architecture.

3 Result markers

3.1 Personnel under training

Student working in the Project:

- Jose Javier Marínez Alvarez, Ph.D. student, is develipong cellular neural networks on FPGAs, studying different architectures, and for differents applications.
- Javier Toledo Moreo, Ph.D. student, is working on augmented reality systems on reconfigurable devices, for low vision problems.
- M. Paula Bonomini, Ph.D. student is working on acquiring and analysing neural data, mainly retinal ganglion cells activity and visual cortex

Jose Javier Marínez Alvarez, Javier Toledo Moreo and M. Paula Bonomini are working in the project since its startup and there exist three more graduate students collaborating with different tasks in the system.

3.2 Publications carried out fully or in part under the Project Sponsorship

Publications [1][6] have to see with the acquisition and analysis of the retinal code. The tools for analysing the neural data are described in [7][8][11][14]. The retina model and the cellular neural network implementation have published in [12][15][16][17][18][19][20][21][22]. Publications [23][24][25][26][27] have to see with the real time augmented reality application for low vision patients. Finally, the application of the retinal model for a cortical visual neurosprostheses have been described in [2][3][4][5][9][10][13]

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3.3 International Projects, Collaboration with national and foreign groups
The Miguel Hernández University group act as coordinator of a EC project (Contract Nº: QLK6-CT-2001-00279) under the quality of life program, with an amount of 2.256.730 Euros.

Project Full Name: Cortical Visual Neuroprosthesis for the blind
Acronim: CORTIVIS
Coordinador: Dr. Eduardo Fernandez
Research Programme: Quality of Life
Tematic Priorities: QOL-2001-6.4, QOL-2001-6.1

Both research groups are working in a proposal to the next Future Emerging Technologies (FET) Program of the EC, oriented to e-Health. The following partners have been collaborating with both groups:

- Dr. Helga Kolb Department of Physiology, University of Utah
  Salt Lake City, USA
- Dr. Josef Ammermüller, Department of Biology and Neurobiology
  University of Oldenburg, Oldenburg, Germany
- Dr. Peter Ahnelt Department of Physiology, Medical School
  University of Vienna, Vienna, Austria
- Dr. Dick Normann, Department of Bioengineering
  University of Utah, Salt Lake City, USA
- Dr. Lyle Graham Centre National de la RechercheScientifique UFR Biomédicale
  Université René Descartes, Paris, France
- Dr Alvaro Pascual-Leone Beth Medical Hospital and University of Harvard
  Boston, USA
- Dr. Pierre Rabischong, Faculte de Medicine
  University of Montpellier, Montpellier, France
- Dr. Leonel Sousa , Instituto de Engenharia de Sistemas e Computadores
  Signal processing systems, Lisboa, Portugal
- Dr. Wim Rutten Department of Biomedical Signal and Systems.
  University of Twente, Netherlands
- Dr. N.F. de Rooij , Institute of Microtechnology
  University of Neuchatel, Switzerland
- Francisco Pelayo, Departamento de Arquitectura de Computadores
  Universidad de Granada, Granada
- Fernando Vargas, Departamento de Física
  Universidad de Murcia, Murcia

3.4 Social collaborations
Both research groups have been invited by **Asociacion Nacional de Retinosis Pigmentaria**, to show their results on the day of this disease in Albacete. A prototype of the system was used by the patients, where they check the functionality of the device, and collaborate in future ref inements.

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