

A Support System for the Diagnosis of Balance Pathologies

Augusto Villa Monte¹, Facundo Quiroga¹, Franco Ronchetti¹, César Estrebou¹, Laura Lanzarini¹, Pedro M. Estelrich^{2,3}, Claus Estelrich³, and Raimundo Giannecchini⁴

¹ Instituto de Investigación en Informática LIDI, Facultad de Informática, Universidad Nacional de La Plata

² Facultad de Ciencias Médicas, Universidad Nacional de La Plata

³ Centro Otorrinolaringológico La Plata

⁴ Facultad de Ingeniería, Universidad Nacional de La Plata
La Plata, Buenos Aires, Argentina

{avillamonte, fquiroga, fronchetti, cesarest, laural}@lidi.info.unlp.edu.ar
martinestelrich@hotmail.com, clausestelrich@yahoo.com.ar
giannerai@yahoo.com.ar

Abstract. Electronystagmography is one of the most widely used diagnostic studies for detecting balance dysfunction. There are various methods that can be used to carry out this diagnostic test, gyratory stimulation being the least invasive and most physiological for the patient. The procedure is based on measuring (analyzing) eye movements in search of certain patterns called nystagmuses.

In this article, we introduce a hardware and software system for carrying out this type of studies that allows the healthcare professional to acquire, view, store, and manage results. The system also provides an intelligent method based on neural networks that can detect nystagmus patterns to help healthcare professionals make a diagnosis. The system is currently being used at a medical office for the detection of balance disorders.

Even though there are similar systems that are commercially available, these are usually very expensive due to their hardware equipment requirements and use of proprietary technology. The system presented here was developed nationally at a very low cost and can be easily adapted to future changes in technology.

Keywords: medical diagnosis, balance pathologies, nystagmus, neural networks, peak detection

1 Introduction

Three complex sensorial systems are involved in the anatomo-physiological mechanism that helps keep balance [2]: the visual system, that relates the body to its immediate surrounding environment (external coordinates); the somatosensory system, that sends information to the brain about the position of each of the different parts of the body in relation to the others (internal coordinates, proprioception); and the vestibular system, that detects body accelerations and

movements. These systems produce a large volume of information that is instantaneously processed by the central nervous system through its complex nerve pathways. Then, from the central control areas, nerve impulses are sent that result in muscle contractions that help keep stability and control body position.

Any disease or disorder, either in any of these systems or their connecting pathways, may cause an alteration in static balance (instability) or dynamic balance (vertigo). Balance disorders[1] mainly appear as dizziness that is usually accompanied by nausea, visual disorders and discomfort. The study of patients with this type of disorders is complex and encompasses many medical specialization areas. Typically, a general clinical exam, a basic neurological exam, an otorhinolaryngological exam, an ophthalmological exam and a neuro-otological exam are carried out.

The neuro-otological exam is a full neuro-physiological test of cranial nerve VIII (vestibulocochlear nerve), which also includes a battery of objective tests to study the vestibular root. In particular, electronystagmography (ENG) tests are of special interest. This type of tests consists in graphically recording specific eye movements (nystagmuses) (Figure 1) with the following special characteristics: slow deviation movement of the gaze axis to the right or to the left, followed by a rapid movement to return to the rest position or straight gaze.

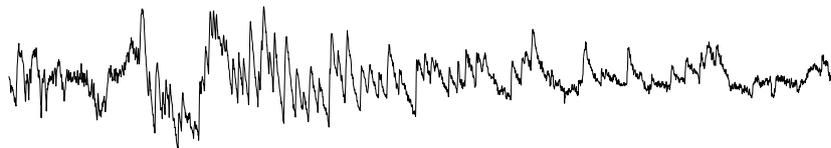


Fig. 1: Typical study signal with right nystagmuses.

The occurrence of these movements is achieved in diagnostic [6] tests by means of various stimuli: changes in position, head and/or entire body rotation, as well as vestibular receptor calorization or retinal stimulation. Once the nystagmuses occur, they are identified and assessed based on various parameters, such as latency, frequency, amplitude, slow component velocity, rapid component velocity, and direction (Figure 2). This task used to be performed manually and carried a significant level of subjectivity on the part of the expert; however, computer analysis can provide an objective, automated method to assess nystagmuses with which such subjectivity can be avoided.

In the following sections, a system to assist in the early detection of balance disorders will be presented; this system was developed in the Country and has been operating for several years at an otorhinolaryngology center in the city of La Plata, Argentina. This system measures the eye movement generated when the patient is rotated while sitting on a chair. This method is less invasive than other alternative procedures, such as introducing hot water inside the ear of the patient, but more costly due to equipment requirements.

Since it was first installed, the system has undergone several technology updates to replace outdated hardware, with the consequent adaptation of the soft-

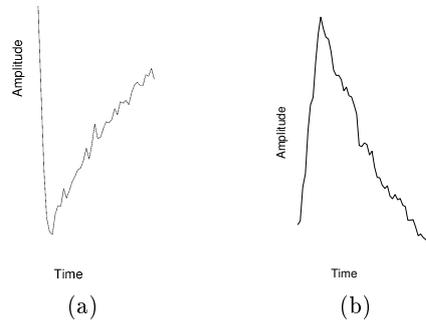


Fig. 2: Parts of a signal corresponding to left and right nystagmus, respectively. The charts show variation in amplitude versus time. In both cases, two nystagmus phases can be identified: during the first one, the *fast phase*, amplitude goes up or down abruptly based on nystagmus direction. During the second one, the *slow phase*, amplitude slowly increases or decreases.

ware developed. Some of the software improvements that have been implemented include an intelligent method based on neural networks aimed at detecting eye pathologies in an adaptive manner (as detailed in Section 3). Since this is a non-deterministic method, the strategy can be adapted for new technologies, thus accommodating various signals from several converter boards.

Several tests are carried out, with durations between 20 and 60 seconds, including biological calibration, right optokinetic test, left optokinetic test, spontaneous nystagmus in the sitting position test, per- and post-rotational nystagmus to the left, per- and post-rotational nystagmus to the right, and pendular test.

This paper is organized as follows: Section 2 describes the system, Section 3 details the nystagmus recognition method, and Section 4 discusses the conclusions.

2 System Description

The system consists of two well-defined subsystems: a hardware system and a software system. Figure 3 shows a simplified diagram. The first subsystem includes:

- A chair, designed by an electronic engineer, where the patient sits while the test is carried out.
- A horizontal LED bar showing a light that the patient must follow with his/her gaze.
- A module that allows the healthcare professional to control the movement of both the chair and the light, and shows the corresponding velocity.
- Four electrodes that are placed on the face of the patient to capture eye movement signals.
- An A/D converter board for data acquisition.
- A basic computer, where the software application is installed.

As regards the software subsystem, it includes:

- A controller for the board.
- Signal acquisition, processing, and storage.
- The database that includes all information pertaining to the patient, including tests and diagnosis carried out.
- The algorithm for detecting nystagmuses.
- The interface for the physician.

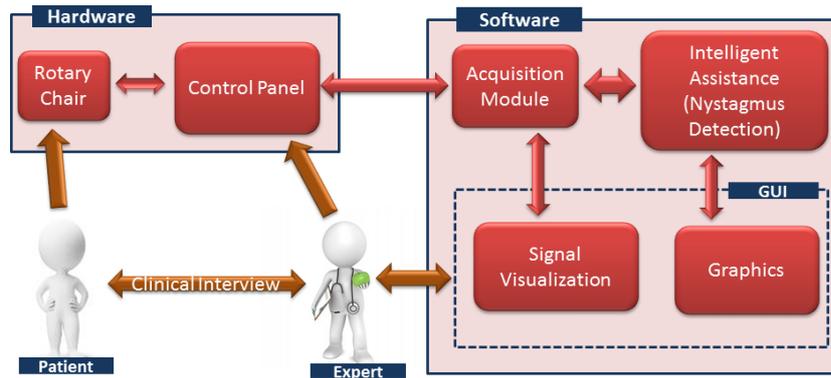


Fig. 3: General diagram of the entire system.

Rotatory chair The patient sits on a chair that can spin for the optokinetic studies, achieving a speed of up to 30° per second. The chair contains four electrodes which are placed on each side of the eyes and in the middle of them. By measuring the changes in the electrical field within the eye, the amount of rotation experienced it experiences can be measured during the study. Since the voltage signals captured by the electrode have very low intensity, an amplifier was attached to the output of the system.

Visual Interface The visual portion is one of the most important components, since it is used by the physician to monitor signal acquisition in real time. Figure 4 shows the window used to view the signal. From top to bottom, the three channels being tested can be seen in it: both eyes combined, right eye, and left eye. The fourth channel corresponds to the velocity of the chair or movement of the light, depending on the type of test. Between tests, the physician can have the patient rest while asking him/her about symptoms and entering the information to the system.

Once the test is finished, it can be re-run as it was originally recorded to observe signal acquisition in real time (*scroll*) without the patient being present. This allows the healthcare professional to free the patient and analyze the signal in greater detail (as if the patient were right there on the rotating chair), taking as much time as necessary to reach an accurate diagnosis. Also, the acquired

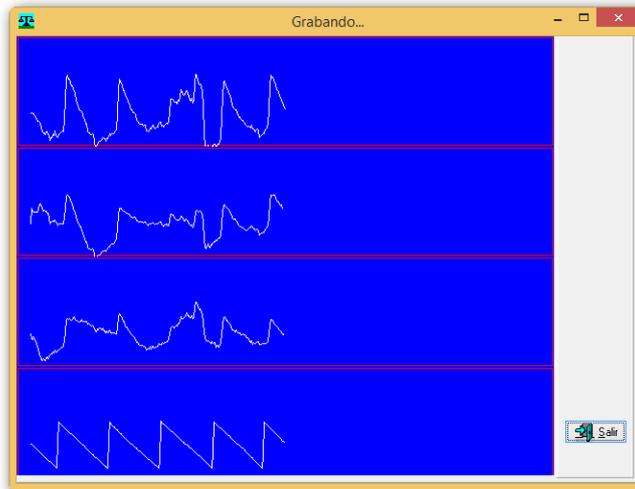


Fig. 4: Signal acquisition and scroll window.

signal can be viewed in full, applying slight scale improvements and smoothing it. This window is shown in Figure 5. As it can be observed, on the upper part of the first three channels there are blue markings that correspond to automatically identified nystagmuses; the physician can then manually add or remove them.

Using the identified nystagmuses, calculations are carried out to build tables and charts that are part of an automated pre-diagnosis. This consists of a text created with default fill-in phrases that the specialist completes to issue the final diagnosis for the patient. Figure 6 shows one of the charts generated by the system.

3 Automatic Identification of Nystagmus

As mentioned above, one of the main goals of the system is to help analyze the signals recorded during the various types of tests that can be performed with the chair; in this sense, it is of interest that the system can automatically identify the nystagmuses in the signals. This functionality helps to maintain a high level of objectivity in nystagmus identification, regardless of the healthcare professional that is in charge of carrying out the test and his/her particular personal situation on any given day. It also streamlines the test itself, which allows providing a more efficient service to the patient and saves specialist time, who can therefore focus solely on the diagnosis. Additionally, the subsystem responsible for carrying out this analysis should be separate from the capture hardware, so that when the latter is updated, there is no need to re-calibrate the system.

Since signals do not have a fixed number of nystagmuses, and these can appear at different positions and with different characteristics, there are two variables that are essential for the automated analysis of the signal: which signal sections correspond to the nystagmus phenomenon in the patient, and the

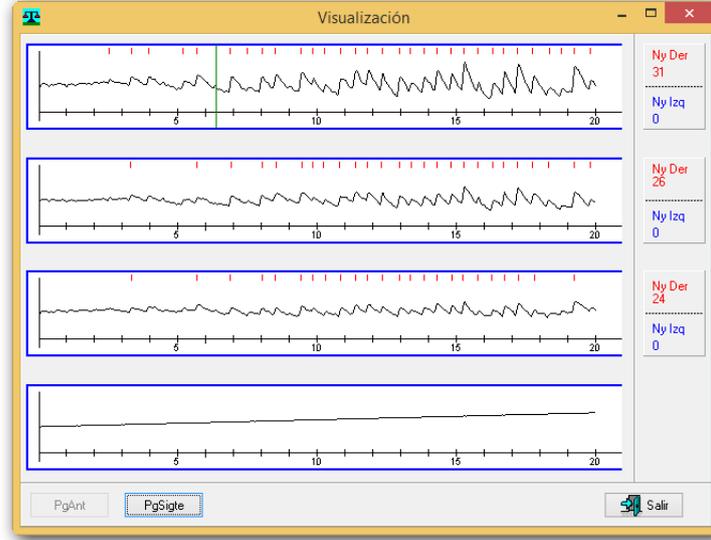


Fig. 5: Signal visualization and marking window.

direction of a nystagmus, i.e., whether any given nystagmus is a left or right nystagmus.

Using signal processing and automated learning techniques, a model was generated to analyze these signals. This model, based on artificial neural networks, allows processing signal intervals and calculating the probability of an interval corresponding to a nystagmus and its direction.

In order to apply the model, a peak detection algorithm is used that allows proposing signal intervals as potential nystagmus to be analyzed. For each potential nystagmus, the model calculates the probability of it being an actual nystagmus and, if the value obtained is above a preset threshold, the corresponding interval is marked as a nystagmus.

In the following subsections, the process used to generate the model and then apply it is described.

3.1 Generation of the Model for Nystagmus Detection

The detection model is based on ProbSom [3], a method developed for recognizing individuals based on voice features.

With the purpose of obtaining a large number and variety of sample nystagmus to train the model, the features that define the nystagmus were analyzed and, from them, a database of artificial nystagmus signals was generated. These artificial nystagmus were fed to the ProbSom for it to learn their features and be able to identify them when presented with a new signal.

For the recognition process to be more effective, instead of using nystagmus data directly, a representation of these data based on their gradient and a windowing scheme was designed.

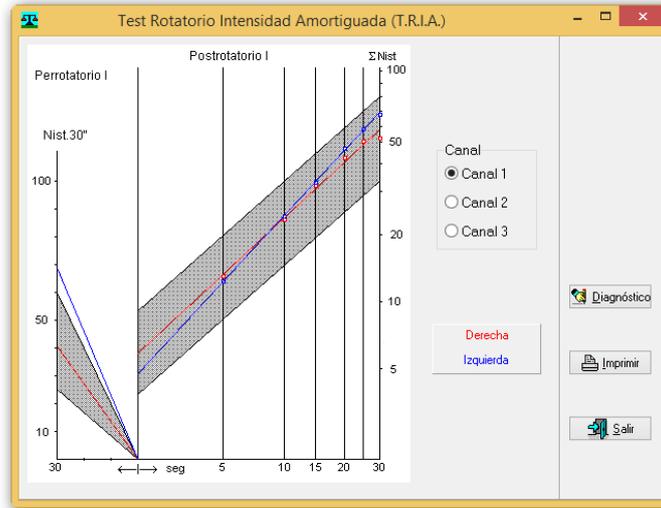


Fig. 6: Rotatory Intensity-Damping Test window.

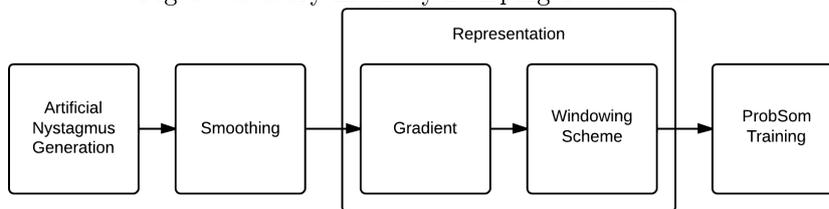


Fig. 7: Diagram representing the process used to train the nystagmus recognition model.

Then, after pre-processing the nystagmus signal, its gradient is calculated to obtain the invariance value corresponding to the mean amplitude of the signal and have a measure of its movement. The resulting gradient vector has as many elements as original sample points are in the signal.

Since ProbSom losses all gradient sequence information, i.e., it only analyzes the properties of the signal regardless of their order, a windowing scheme is used to include this temporal relation to signal properties. Thus, based on a signal that has M samples, V -sized windows can be generated by taking V consecutive samples from the signal. In particular, for a signal with M samples and V -sized windows, a total of $M - V + 1$ windows are generated.

As already mentioned, the recognition model used to detect if any given portion of the signal corresponds to a nystagmus is based on ProbSom. The essential idea of this method consists in training a Self-Organizing Map (SOM) [4], a type of associative neural network, with small nystagmus portions, so that the model can learn their features. Then, each neuron on the network is associated to one of these nystagmus features, and each feature is in turn associated to a class (left nystagmus, right nystagmus, non-nystagmus). In particular, the probability of a

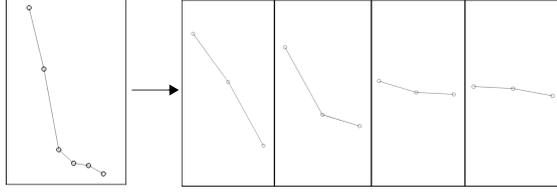


Fig. 8: Generation, from signal gradient, of $M - V + 1 = 4$ windows for a signal with $M = 6$ and window size $V = 3$.

nystagmus belonging to one of the classes is determined, given that it presents a certain feature.

In this case, each feature consists in the signal having some of the windows mentioned in the previous section.

This training process is carried out using model nystagmuses; in particular, our system uses artificial nystagmuses. Then, during the classification stage of a real signal, the model will be able to take a portion of that signal and decide whether it corresponds to a nystagmus or not and, if it does, it will be able to decide what type of nystagmus it is.

3.2 Application of the Nystagmus Detection Model

With the previous model to detect if a portion of a signal corresponds to a nystagmus and if identified nystagmuses are left or right nystagmuses, the entire signal can be processed to detect all nystagmuses present in it.

Detection consists of three parts. First, the signal is pre-processed to remove undesired noise and inter-subject differences, as well as those differences caused by varying experimental conditions. Then, a traditional peak detection algorithm is run to find maxima and minima within the signal, and, using this information, the signal is segmented into intervals that represent potential nystagmuses. Finally, the recognition model processes each of these intervals to validate if they effectively correspond to a nystagmus and, if they do, it determines their directions. These steps are described in detail below.

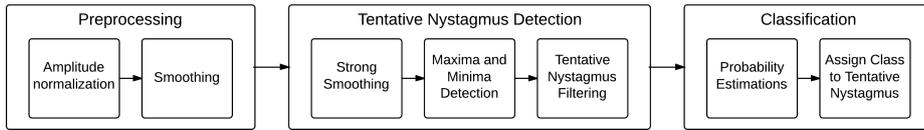


Fig. 9: Three stages of the nystagmus detection process in a signal.

The signals originated from electronystagmographies present systematic differences caused by inter-subject variations and variations in the conditions for carrying out the test, such as mean room lighting. Therefore, signal amplitude is normalized for the interval $[-1, 1]$ in order to standardize the meaning of this variable.

Additionally, the signal contains noise from errors that are inherent to the capture system, as well as undesirable movements made by the patient. Since the removal of such noise at this stage is also important to prevent the deformation of the natural peaks present in the signal, a Savitzky-Golay filter [5] was applied in a window of size $w = 13$, with a polynomial of order $n = 2$.

It should be noted that in this case, the entire signal is pre-processed, not just a portion that corresponds to a nystagmus.

After the signal has been normalized, it is segmented into potential nystagmus, which will be then confirmed or discarded by the detection model. Segmentation is based on the detection of peaks, using them as indicative of the beginning and the end of a nystagmus, which helps save calculation time, and filtering those signal portions that do not correspond to a nystagmus.

Thus, signal minima and maxima are identified by means of a traditional peak detection algorithm. However, before this step, the signal is strongly smoothed once again to increase to remove spurious maxima and minima, leaving only the most salient peaks.

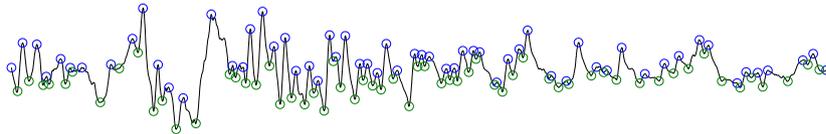


Fig. 10: Maxima and minima detected in a signal that has undergone two smoothing processes.

Using these maxima and minima, potential intervals are identified that could correspond to nystagmus in the original, non-smoothed signal. In the case of nystagmus to the right, intervals with two minima around a maximum are detected, and the opposite for nystagmus to the left, thus generating two sets of potential nystagmus, one for each type. These intervals are filtered so that they do not overlap.

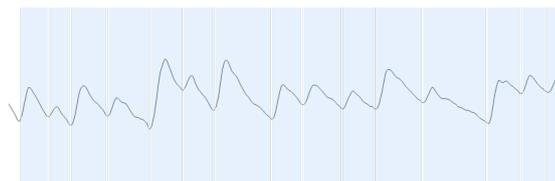


Fig. 11: Potential nystagmus to the right (blue rectangles).

For the application of the classification model, the segmented signal portions corresponding to potential nystagmus are pre-processed and the representation described in Subsection 3.1 is calculated for each portion. Then, the ProbSom model uses these representations to calculate the probability that these signal

portions belong to the *left nystagmus* or *right nystagmus* classes, or to sort them as belonging to any of the rejection classes.

It should be noted that only potential nystagmuses to the right, i.e., nystagmuses that are formed by a maximum peak between two minimum peaks, are considered for classification as right nystagmuses, and vice-versa for left ones.

Thus, in the case of potential right nystagmuses, the system confirms that they are indeed nystagmuses if the probability calculated by ProbSom for the class *right nystagmus* is at least double than for the rest of the classes. The same criterion is applied for potential left nystagmuses.

4 Conclusions

A system that helps diagnose balance pathologies has been presented. It is being successfully used at a doctor's office, assisting in performing of dozens of tests each month.

The system allows the physician to capture and store the signals recorded during an electronystagmography and associate them to a patient and a set of studies so that patient history can then be reviewed with information from all the tests that he/she has undergone.

Additionally, the signals captured during the electronystagmography are automatically analyzed to identify nystagmuses and this information is presented to the health-care professional to help him/her reach a faster and more objective diagnosis. Using this intelligent processing, the values obtained in the test are compared to those corresponding to normal reference values, so that the physician can quickly determine if the patient suffers some pathology. This processing is independent from the hardware equipment used for the capture.

It should be noted that the system is a national development with a low associated cost, versus the significantly higher costs of other commercially available products with similar functionalities that are produced abroad.

References

1. Brandt, T., Daroff, R.B.: The multisensory physiological and pathological vertigo syndromes. *Ann Neurol* 7(3), 195–203 (1980)
2. Claussen, C.F., Bergmann, J.M., Bertora, G.: *Equilibrimetría y Tinnitusología Práctica* (2009)
3. Estrebou, C., Lanzarini, L., Hasperue, W.: Voice recognition based on probabilistic som. In: *Latinamerican Informatics Conference. CLEI 2010. Paraguay. October 2010.* (2010)
4. Kohonen, T.: *Self-organizing maps*, vol. 30. Springer (2001)
5. Savitzky, A., Golay, M.J.: Smoothing and differentiation of data by simplified least squares procedures. *Analytical chemistry* 36(8), 1627–1639 (1964)
6. Serra, A., Leigh, R.J.: Diagnostic value of nystagmus: spontaneous and induced ocular oscillations. *J Neurol Neurosurg Psychiatry* 73(6), 615–8 (2002)