Automatic and Adaptive Fitting of the Cochlear Implant by Using Interactive Evolutionary Algorithms

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ABSTRACT: *Cochlear Implants (CI) are electronic devices that stimulate directly the auditory nerve to allow totally deaf patients to hear again. However they are more and more difficult to tune. The goal of this paper is to propose an automatic fitting method adaptable to different sound environments by using an interactive evolutionary algorithm. Real experiments on volunteer implanted patients are presented, which shows the efficiency of interactive evolution for this purpose. In the future, our goal is to add a piece of software to the CI signal processor that will automatically choose the best parameters setting depending on the class of the sound environment picked up by the microphone.*

Keywords: Interactive Evolutionary Algorithm, Cochlear implant, Fitting, Sound environments

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1. Introduction

For centuries, people believed that only a miracle could restore hearing to the deaf. It was not until forty years ago that scientists first attempted to restore normal hearing to the deaf by electrical stimulation of the auditory nerve. Nowadays, a prosthetic device, called cochlear implant, can be implanted in the inner ear and can restore partial hearing to profoundly deaf people. A cochlear implant (CI) is a surgically implanted electronic device that provides a sense of sound to a person who is profoundly deaf or severaly hard of hearing. CI may represent a potential solution for patients who suffer from partial or total deafness and whose cochlea remains functional [1]. The success of cochlear implants can be attributed to the combined efforts of scientists from various disciplines. Each of these disciplines contributed to various aspects of the design of cochlear prostheses. However, finding optimal settings for the implant is a very difficult task even for an expert, mostly because patients are very different and show great difficulty in expressing their sensations. This complexity is increased by the fact that there are many parameters to tune.

Many factors play a key role on the result: the cause of 0 deafness, the amount of time the patient has been deaf before he is implanted, his/her age, etc, but also the values of the numerous parameters of the signal processor connected to the implant.

It is difficult to find the correct values for the parameters because 0 patients are different: the cochlear implant electrically stimulates the auditory nerve that is directly connected to the brain area devoted to hearing. Biologic neural networks are highly plastic. If auditory neurons are not stimulated for a long period of time, they can be reassigned to some other task and some patients have been known to “see” colors whenever their auditory nerve was electrically stimulated.

In most of the cases, however, many tiring and long fitting sessions are needed, during which an expert tries to determine the set of parameters that will allow the patient to make the most of his/her cochlear implant. In many cases, after three to ten sessions, the patient is satisfied and obtains good scores at blind speech tests. For some patients, unfortunately, the story is less idyllic. After many fitting sessions over several years, some do recognize words, while others still hear meaningless screeches and beeps.In the worst cases, the patient prefers the sound of silence and simply switches off the device.

Takagi [2] and Duran [3] used Interactive Evolutionary Algorithms (IEA) within the framework of the regulation of hearing aid with prostheses. The patients equipped with prostheses have light deafness while the carriers of IC are affected by deep or total deafness. The aims are very different particularly in terms of understanding words. The evaluation of the individuals concerns only the notion of 0 hearing comfort, the understanding of words is not approached. Moreover, the evaluation of 0 hearing is not realized in real situations, i.e. the sound environments of the patient. The same evaluation mode is conducted by both authors, it is based on the “good” or the “bad” response [4]. The developed algorithms do not implement specific strategies (i.e. the word comprehension, the comfort, the intensity, etc, are not taken into account) and only classic genetic operators are used. These works contribute to help the fitting of hearing aids, but they do not propose an automatic fitting.

This paper is organized as follows:

In section 2 we present the CI and describe the current expert parameter fitting. In section 3, we detail the different steps of the proposed automatic CI fitting method. Section 4 is devoted to the experiment results. Finally, in section 5, after concluding our work, we mention some of the further tasks and perspectives that we must deal with.

2. Cochlear implant

2.1 Parts of the cochlear implant

The implant is surgically placed under the skin behind the ear. A cochlear implant is a small, complex electronic device that can help to provide a sense of sound to a person who is profoundly deaf or severely hard-ofhearing. The implant consists of an external portion that sits behind the patient’s ear (cf. figure 1) and a second portion that is surgically placed under his/her skin (cf. figure 2). The basic parts of the device include:

An external part:

- A microphone which picks up the sound from the environment.

- A Digital Speech Processor (DSP) which selectively filters the sounds to prioritize audible speech and sends the electrical sound signals through a thin cable to the transmitter.

- A transmitter, which is a coil held in position by a magnet placed behind the external ear, and transmits the processed sound signals to the internal device by electromagnetic induction.

An Internal part:

- A receiver and stimulator secured in bone beneath the skin, which converts the signals into electric impulses and sends them through an internal cable to electrodes,

- An array of up to 22 electrodes wound round the cochlea, which sends the impulses to the nerves in the scala tympani and then directly to the brain through the auditory nerve system. There are 4 manufacturers for cochlear implants, and each one produces a different implant with a different number of electrodes. In this study, the CI employed is manufactured by MXM11 and the number of electrodes in this case equals 15. The number of channels is not a primary factor upon which a manufacturer is chosen; the signal processing algorithm is also another important block.

An implant does not restore normal hearing. Instead, it can give a deaf person a useful representation of sounds in the environment and help him or her to understand speech. A cochlear implant is very different from a hearing aid. Hearing aids amplify sounds so they can be detected by damaged ears. Cochlear implants bypass damaged portions of the ear and directly stimulate the auditory nerve (see figure 2). Signals generated by the implant are sent by way of the auditory nerve to the brain, which recognizes the signals as a sound. Hearing through a cochlear implant is different from normal hearing and takes time to learn or relearn. However, it allows many people to recognize warning signals, understand other sounds in the environment, and enjoy a conversation in person or by telephone.

[1] Labs: http://www.neurelec.com/index_fr.html

2.2 Cochlear implants fitting methodology with an expert

Following a recovery period of three to six weeks, the patient will return to the audiologist for fitting O the external components. This first fitting is often referred to as the initial stimulation or hook-up. An audiologist programs the device during the fitting process. The aim of cochlear implant fitting is to optimize an artificial electric stimulation of the auditive nerve in order to improve the communication. Speech characteristics are put forward so as to improve speech recognition [5].

Figure 1. Cochlear implant: (a) external components (antenna, microphone, speech to processor) and (b) internal components (electrode array and receiver-stimulator)

The list of the cochlear implant fitting parameters is:

- Channel: a combination of electrodes (sources and sinks) that is typically associated with the output of one of the spectral analysis bandfilters.

- T level: Threshold level – the minimum stimulation level (current) that the subject can detect (i.e. hear) on a channel.

- C level: Comfort level – the loudest comfortable stimulation level (current) on a channel.

- Number of channels: The total number or stimulation channels available (It depends on the device and also on the number of electrodes that are usable for any given Implant recipient).

- Compression curve: The steepness of the infinite instantaneous compression curve that maps filterbank output to electrical dynamic range.

- FAT: The Frequency Allocation Table determines which frequency range is connected to which electrode/channel.

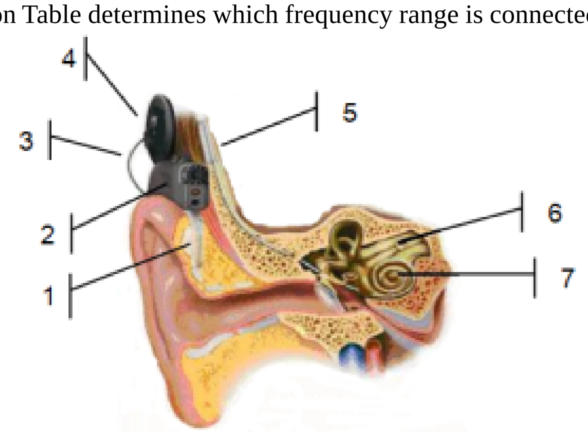

Figure 2. a cochlear implant: all implant devices have the following features in common: the sound is collected by a microphone (1) and (2) sent to electronic components within a DSP (2). The speech processor analyzes the input signal (sound) and converts it into an electronic signal (electrical). This code travels along a cable (3) to the transmitting coil (4) and is sent across the skin via frequency modulated (FM) electro-magnetic waves to the implant package (5). Based on characteristics of the code transmitted to the internal device, electrode contacts within the cochlea (6) provide electrical stimulation to the spiral ganglion cells and dendrites extending into the modiolus. Electrical impulses then travel along the auditory nerve (7), ascending auditory pathways to the brain

- Stimulation mode: it defines how the channels are formed, for instance we can stimulate between two neighboring intra-cochlear electrodes (bipolar mode) or between an intra-cochlear and an extra-cochlear electrode (monopolar). Monopolar stimulation is the most commonly-used mode. One of the main problems in implant fitting, unlike the fitting of hearing aids, is that the inter-subject variation of T and C levels is much larger than the average dynamic range (C-T) for an individual subject. This means that a map for one recipient may be either inaudible, or far too loud for another individual. When a map is far too loud, this may even cause a painful stimulation of non-auditory nerve fibers, hence it is something to avoid at all times. The latter remark is especially true for children because over-stimulation can create anxiety about the implant/hospital/audiologist and in this way hamper the validation process. This means that it is not possible to start with a 'default' fitting in all subjects. For example: the average T level can vary between roughly 100 and 1000 mA, a 20 dB difference, while the average dynamic range is only about 4 dB.

- T and C levels are by far the most important map parameters, since this is what makes a map audible/comfortable. All the other parameters can be considered fine-tuning for audio quality. It will focus primarily on T and C level settings.

- The classical way of setting map levels is the following procedure, which is based on single-electrode psychophysics. The clinician stimulates a specific electrode with a burst of pulses that occurs at the desired rate. This stimulation starts at a very low level and the stimulation is slowly increased in small steps. The recipient is asked to report any auditory sensation. The stimulation is increased until the recipient hears the sound, then, using finer steps, an up-down procedure (very similar to audiometry) is used to find the threshold of sensation for this burst. The level at the threshold is referred to as T-level. Once T-level is established, the clinician increases the stimulation in small steps (1 dB) until the recipient indicates that the sound is loud but comfortable. This is referred to as C-level. The above procedure is repeated for all the electrodes on the array.

- When all the electrodes are tested, generally a balancing procedure is performed to make sure that all C-levels generate approximately the same loudness, which, in turn, ensures that equal-leveled audio input generates equal-leveled electrical stimulation. When this is done, the implant is put into speech processing mode, and the map is tested with speech input. If needed the clinician can globally lower or raise the Tand/ or C-levels to adjust the loudness perception of live speech.

- The traditional method of fitting presents numerous inconveniences. Many factors influence the tuning, among which the patient's general health state and age. The number of tested electrodes and the length of the fitting session depend very much on how long the patient is receptive and able to collaborate. The clinician uses his expertise to submit new settings to the patient. The choices only concern a few parameters. No drastic changes are performed and the different settings submitted to the patient are only variations on the same original parameters, simply because the clinician is a human being intrinsically unable to draw conclusions from tens or hundreds of radically different settings. The great number of parameters, the disparity of patients and the difficulty to communicate with the patient, and finally the time taken by the process of modifying a single parameter, are obstacles to the methods based on medical expertise, which explain why it is difficult for experts to find an optimum fitting for a given patient [6].

3. Proposed solution: automatic and adaptive fitting

The proposed solution is different from conventional fitting methods. The aim is the development of an innovative and generic fitting procedure for the adjustment of aids that does not depend on the knowledge of the signal processing used by a particular aid. The new method takes into account the preference of the hearing-aid user [7].

One important aspect that needs to be taken into consideration is the subjective nature of the interactions that take place with the patients. Evaluating the different fittings of the DSP and the cochlear implant depends on the patient's ability to detect different perceptions or to perceive different sensations which can sometimes be quite difficult to express. Furthermore, evaluating the success of a cochlear implant can be quite biased and especially when the Pygmalion effect comes into force. The Pygmalion effect means that some patients tend to place surgeons and experts on a pedestal because they have years of experience in adjusting the fittings of the cochlear implants and of the DSP and because they are the ones who give the patients the ability to hear.

The user has to compare carefully selected pairs of different hearing-aid settings, and to choose the one that sounds better. The user's preferences are interpreted by an interactive evolutionary algorithm that efficiently chooses the aid settings for the next comparison, and eventually finds the optimal hearing-aid settings.

In order to achieve an automatic and adaptive fitting of cochlear implants with evolutionary algorithms, several stages must be performed:

1. The medical team must determine with the patient a number of common environments for which the patient needs a specific fitting, for instance: home, work, supermarket, cinema, etc. The number of specific environments should be limited (generally limited to 10), because for each of the specified environments, a special set of parameters needs to be found for the cochlear implant, and finding a good set of parameters can be a long and difficult task.

2. For each of the specified environments, the patient must take a number of sound samples to bring back to hospital. A sound sampling software program is developed on Personal Digital Assistant (PDA) that the patient plugs directly into the CI processor in order to sample the exact sound that is received by the processor. 30 seconds seem to be a correct duration, so that when the patient is out with the PDA, he has 30 seconds to press on the button after realizing that some interesting sound has occurred.

3. In parallel, the different samples must be analyzed to extract some common features, so that a classifying algorithm can determine in which category the sound environment that is surrounding the patient falls (Class 1, Class 2, Class 3,…, Class 10).

4. Specific (CI) parameters must be found (P1, P2, P3,…, P10), to deal with each of the specified environments with the help of an Interactive Evolutionary Algorithm (IEA).

5. Finally, the characteristics and parameters for the different environments must be uploaded into the cochlear implant (or hearing aid) processor, along with a signal processing program that will automatically choose the correct parameters (P1, P2, P3,…, P10) to match the environment in which the patient is evolving.

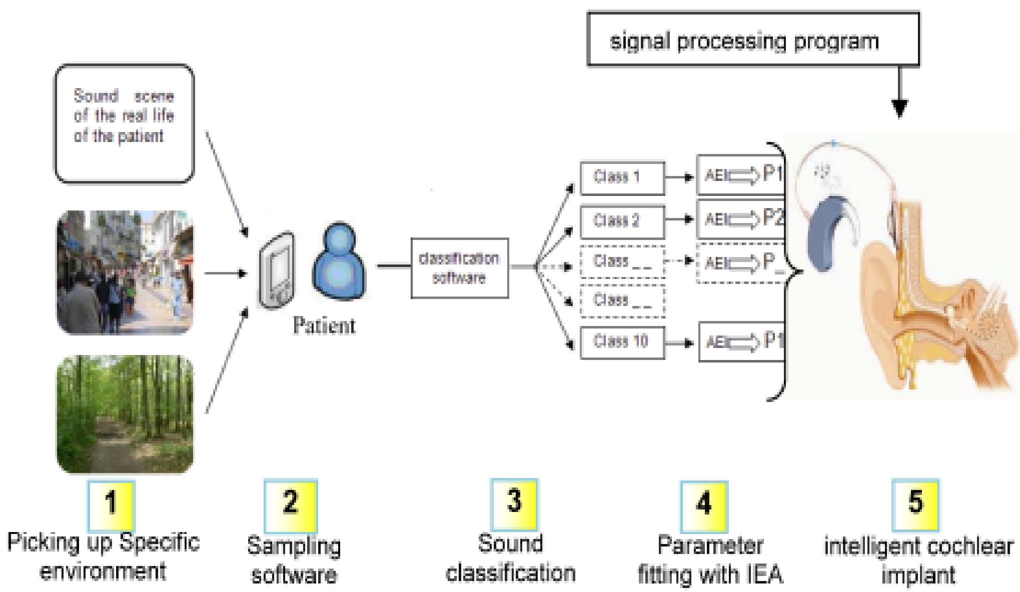

Figure 3. A block diagram of the proposed method for cochlear implant fitting

3.1 Classification of sound environment

3.1.1 Characterization of a sound environment

We distinguish two steps in the problem of "sound environment classification". The first step is the extraction of the characteristics, in order to build the space representation. The second step is to find a classification method which allows to fit each point of this space with a probability of being in a specified family.

The characteristics motivated by the human perception such as the spectral characteristics (the loudness or the pitch) can describe all kinds of sounds because the human brain uses these characteristics in order to recognise the sounds from 0 everyday life.

For this work we will analyse the frequential content at each dyadic scale because the implant performs the same kind of analysis. We will use a wavelet transform in order to perform a multiscale analysis [8]. We could use a simple Fourier Transform but we prefer to keep the possibility to use the time localization provided by the wavelet transform for a future work. In fact, a wavelet analysis allows to adjust the width of analysis windows, and achieves a perfect localization in time and frequency. Logically, temporally extended windows are used to study low frequencies, while narrower windows are used for higher frequencies. This localization property makes the wavelet theory predominant in several areas of signal processing [9].

3.1.2 Continuous Wavelet Transform (CWT)

A continuous wavelet transform (CWT) is used to divide a continuoustime function into wavelets. Unlike Fournier transform, the continuous wavelet transform possesses the ability to construct a time-frequency representation of a signal that offers a very good time and frequency localization.

3.1.3 Discrete Wavelet Transform

The Discrete Wavelet Transform can be obtained thanks to the discretization of the parameters of resolution (a) and position (b).

$a = a_0^{\,m}$ with an integer, a resolution step greater than 1 and $b = nb_0 a_0^{\,m}$ with an integer and $b_0 > 0$.

We therefore obtain:

$$\omega_{j,k}(t) = a^{-\frac{j}{2}}\,\omega\left(\frac{t - nb_0 a_0^{\,j}}{a_0^{\,j}}\right) = a^{-\frac{j}{2}}\,\omega(a_0^{-j}t - kb_0)$$

The discrete wavelet transform of a f signal is given by:

$$C_{j,k} = a^{-\frac{j}{2}}\int_{-\infty}^{\infty} f(t)\omega(a^{-j}t - kb_0)\,dt$$

Furthermore, if a = 2 and b = 1, the transform is called “dyadic.” We then have:

$$C_{j,k} = 2^{-\frac{j}{2}}\int_{-\infty}^{\infty} f(t)\omega(2^{-j}t - k)\,dt$$

Let

$$\omega_{j,k} = 2^{-\frac{j}{2}}\,\omega(2^{-jt} - k) \text{ and } \phi_{j,k} = 2^{\frac{j}{2}}\phi(2^{j}t - k)$$

The $\phi_{j,k}$ family will allow us to represent approximations of the analyzed function, while wavelets will be used to represent details. We get a tiling of the time-frequency space called a dyadic grid.

3.1.4 Calculation of the energy

On a given scale, the energy of the signal can be obtained from the continuous wavelet transform and to be more precise we can compute the energy of the scale by adding the squares of the wavelet coefficients of the continuous transform to this scale:

$$E_a^2 = \int [CWT(a,b)]^2\,db$$

If we use the discrete wavelet transform, we get:

$$E_j^2 = \sum_{k=1}^{2^{j-1}} [C(j,k)]^2$$

3.1.5 Characterization of a class by its energy content

Let us consider the $S1$ sound environment. The patient records a collection of *.wav files, that are chopped into a family of n_1 sub signals of 2^{14} points. If we compute the discrete wavelet transform of these (signals and the energy of each of the obtained frequency bands during multi-resolution analysis ($\log_2 = 2^{14} = 14$), one then gets n_1 vectors of 14 coordinates. The class will be characterized by the mean of these vectors.

3.2 Evolutionary algorithm

Evolutionary Algorithms (EA) are a modern implementation of Darwin’s principle of the survival of the fittest. EA are computational models inspired by evolution. These algorithms encode potential solutions to a specific problem in a chromosome. Each of these chromosomes represents an individual. Decoding and evaluating the chromosome of an individual indicates how good this potential solution actually is. This is known as the fitness of an individual. The group of individuals is called the population.

At the start of the algorithm a population is set up. The evolutionary process then decides which members of the population are most likely to reproduce, based on the fitness of the solution they contain. The individuals that represent a better solution to the target problem are more likely to reproduce than those that represent a poor solution. After reproduction a new population enters the same process. This process is repeated using cross-over, mutation and selection, until certain given constraints are satisfied or until a given amount of populations have been examined. Crossover and mutation principles are further discussed in section 3.3.1. Solving a problem using an Evolutionary Algorithm depends on a few basic factors. It must be possible to determine the fitness of a solution, and to determine which solution is close to an acceptable solution. Evolutionary algorithms assume that combining two good individuals will probably create even better offspring [10], [11], [12].

3.2.1 Interactive evolutionary algorithm for CI fitting

Most (if not all) medical decisions can be formulated as a search in some appropriate space. Our medical search spaces are very large and complex. On the one hand, the models involve too many non-linear and uncertain parameters to be treated analytically. On the other hand, medical experts are usually not available, or simply do not collaborate in translating their experience into a usable decision tool [3].

Unfortunately, implant fitting can be considered as an NP-complete problem, due to the fact that the reaction of a specific patient to a set of parameters is difficult, if not impossible to predict. There is no mathematical function or direct bijective relationship between the observed symptoms or comments from the patient and specific parameter settings, even if some rules of thumb can be deduced from experience: apparently identical symptoms can lead to different settings depending on the patient (age,cause of deafness, general health state, etc).

We are in the presence of a problem of non-linear optimization, with many local optima [14].

The problem is that the only known deterministic method that can be applied on such problems is an exhaustive exploration of all the possible values for all the parameters. Stochastic methods are used for complex problems where deterministic methods are inefficient (non-derivable functions, noisy functions, intractable solutions, exponential complexity, etc.) [14].

Among the numerous stochastic methods that are available, Evolutionary Algorithms (EA) seem well-suited for this specific problem. EA are known to widely explore the search space thanks to the fact that the population is made of several individuals. Other techniques, such as simulated annealing, are equivalent to optimizing only one individual, meaning that only a small part of the search space is covered. Therefore, Evolutionary Algorithms are less easily trapped into local optima, which is a very interesting feature in the problem of optimizing cochlear implants fitting.

Another advantage is that Evolutionary Algorithms do not need a formal mathematical representation of the problem that has to be optimized: they only need a fitness value for a proposed individual, which can be given interactively by the patient. Figure 4 illustrates the different steps of an IAE.

1. An initial population is created and then evaluated (by a user in the case of an interactive algorithm) with the aim of creating a population of parents.

2. If we are not satisfied (non-verified stop criterion), then *n* parents are selected (from the best parents) to create *m* children with the help of the genetic operators.

3. The new individuals who are created are then evaluated.

4. Finally, the weakest individuals are eliminated thanks to the use of the replacement operator. This phase makes it possible to reduce the size of the population to its initial size. The loop is restarted from point 2 with the new generation of parents.

3.2.1.1 Genome structure

Among the hundreds of parameters that can be modified, the expert clinician suggested starting with determining the optimal T and C values for each electrode. Before experimenting with the EA, the clinician determines the maximum intensity range for each electrode to define an envelope within which the Evolutionary Algorithms could suggest values. These values will be called Te and Ce. With the MXM 15 electrodes CI used for this experiment, the genome is therefore an array of only 30 real values, meaning that the chances to find a good fitting are much higher, representing the T and C values for each of the n electrodes of the implant.

3.2.1.2 Initialization

There is one major constraint that needs to be respected: the maximum threshold limit for the stimulation of each of the electrodes must not be exceeded. For each new patient the first appointment with the expert who adjusts the fittings of the cochlear implant is to determine the maximum threshold level that should not be passed for each electrode. A minimum intensity level is also determined because if an electrode is stimulated under this intensity level it means that a patient is unable to hear anything. The initialization of each individual involves the following procedure: for each of the 15 electrodes, two random values are taken within the respective [min, max] interval (this interval is determined during the psychophysical test). The lowest value in the interval is taken to be the T threshold and the highest value in the interval is taken to be the C threshold.

3.2.1.3 Selection of the parents

A selection by "tournament" is used [15]. Parents' selection is different from the replacement stage in that it can select an individual several times. Whenever a child must be created, two different individuals are selected among the parents' population, that can be selected again to create another child [16]. A selection favoring the best individuals is operated among the parents and offspring populations, in order to reduce the total number of individuals. This reduced population will be the parent population of the next generation.

3.2.1.4 Crossover

The genes are real values, which could have suggested some kind of barycentric crossover (such as used in Evolution Strategies), where each gene of the child is an average between the two genes of his parents. But since it is intervals that must be evolved, this type of crossover would have led to reduce the intervals progressively. The chosen crossover is that of genetic algorithms which exchange the parents' genes after a crossover point (locus) that has been selected randomly. A mono-point crossover has been chosen, as a multiple crossover would have had a tendency to break efficient genomes, and would have turned the crossover into a kind of macro-mutation.

3.2.1.5 Mutation

Mutation is also called with a 100% probability on each created child. In the proposed algorithm, each gene has a 10% probability to be mutated. Since there are 30 genes, each child undergoes 3 mutations in average. This may seem important, but due to the large epistasis, modifying a threshold on the global genome only has a limited influence on the global evaluation. This high mutation rate allows to keep a reasonable exploratory character to the algorithm, in spite of the very small number of evaluations.

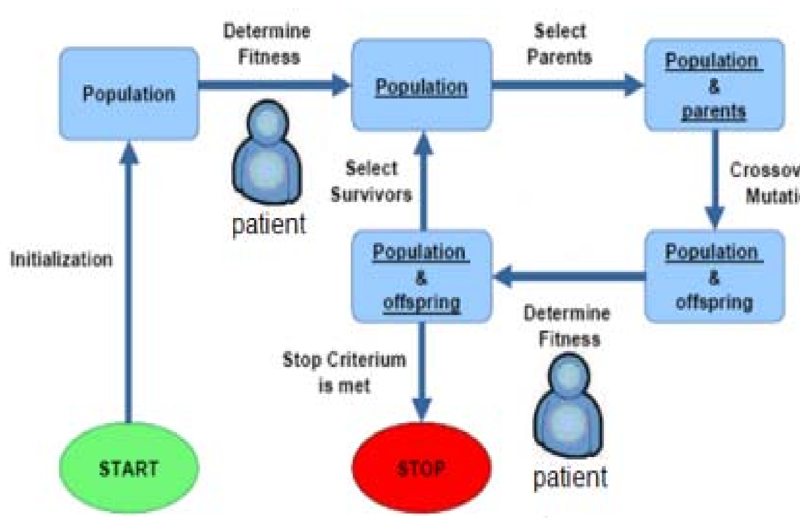

Figure 4. interactive evolutionary algorithm (IEA)

3.2.1.6 Replacement

A Steady State like replacement is used, i.e. with a very small number of children per generation, in order to promote a fast convergence. During a strict Steady State replacement, only one child would be created, that would replace the worst of both parents. Since we decided to have several children per generation, it is a replacement scheme that is used, with only 2 or 3 children per generation (where Evolution Strategies usually create more children than the number of individuals in the population) [12].

3.2.2 Fitness

In an interactive Evolutionary Algorithm, a human user evaluates the different individuals proposed by the algorithm. As far as the optimization of the parameters of a cochlear implant is concerned, it is the patient who evaluates the fittings of the implant, this evaluation being based on a particular series of words or syllables. It is therefore not possible to rely on a large number of patient evaluations, because in a domain like this the physiological and physical behavior of the patient can also influence the results. It is also necessary to take certain psychological aspects into consideration. For example, if the convergence speed of the algorithm is correctly regulated for the 100 evaluations, it implies that eight hours are needed to carry out the evaluation. Thus the patient could be disheartened by this period of time of eight hours which is much too long to carry out a process of evaluation. The eight hours of evaluation do not have to be carried out in one session and a solution to this problem involves breaking the experiment into several partial optimizations (known as runs). A restart is the term used to start the next run [17].

Up to now evaluating a patient’s ability to understand spoken language to test the new fittings of the patient’s cochlear implant has been carried out in two different ways. The first method involved sending the patient back home with the new fittings stored in the *P1* memory and the previous fittings stored in the *P2* memory. This meant that the patient was able to compare the two different fittings in the comfort of their own surroundings. The other method involved a speech therapist who carried out an evaluation on patients by using intensive tests which took over one hour to be completed [4].

However, it was impossible to apply an interactive Evolutionary Algorithm [15] to either methods. As a result, a new evaluation protocol was developed and this method of evaluation involved using sentences that were graded in levels of difficulty. These sentences were taken from Professor Lafon’s cochlear lists [19] and contained syllables which were representative of the French language. Using such sentences made it possible to evaluate any cochlear pathologies. Ten sentences (a total of 78 words) were chosen to evaluate a patient’s understanding of the spoken language. The original sentences in French can be seen below; a translation of each sentence into English is given in brackets.

Se réveiller chaque matin peut être un plaisir.
(Waking up each day can be a pleasure)

La cravate garde encore du prestige pour certains.
(The tie remains prestigious for certain people)

Il ne restait que de l’eau à boire.
(There was only water left to drink)

Il s’est fait aider pour porter ses bagages.
(Someone helped him to carry his bags)

Les chiens gardent les villas contre les voleurs.
(The dogs are protecting the villas against thieves)

Il existe des perles fines et des perles de culture.
(There are both natural and man-made pearls)

L’enfant appelait sa mère parce qu’il avait peur.
(The child called his mother because he was afraid)

On aspire et expire par la bouche.
(We breathe in and out through our mouth)

L’intelligence permet à l’homme de comprendre.
(Intelligence enables man to understand)

Les parfums doivent avoir une odeur agréable.
(Perfumes should have a nice smell)

Maximizing the understanding of a patient is, of course, one of the main objectives of the evaluation process but it is also very important to remember 12 that the cochlear implant needs to be adjusted comfortably for the patient, so he can use it in his everyday life.

The overall evaluation is therefore the weighted mean of the comfort level of the cochlear implant and of the patient's understanding. For the tests described in the next section, the comfort mark is multiplied by 2.2, which means that the overall comfort mark is out of 22. The total number of words that were recognized (out of 78) is added to this mark in order to get a total overall mark of 100. This total mark out of 100 will be used as the patient's evaluation for the Evolutionary Algorithm. The mark that is given for patient understanding is the predominant mark and the comfort mark tends to be forgotten about.

The evaluation procedure normally lasts about four minutes. A period of four minutes is clearly not enough to get a true evaluation of a patient's ability to hear. However, this procedure makes it possible to carry out 100 tests in six hours forty minutes (in other words one hour twenty minutes per run, if the 100 evaluations are divided into five runs). If an Evolutionary Algorithm can be applied to this procedure and improve the fittings of the cochlear implant in just 100 evaluations then its objective has been reached. The aim of this reduced evaluation protocol is different from the complete evaluation protocol

Sound Families	Carradio	Crossroads	Birds	Schoolyard	Lawnmower	Supermarket	**number of test samples**
Car-radio	100%						**8**
Crossroads		86%			7%	7%	**13**
Birds			100%				**7**
School-yard				100%			**11**
Lawn mower		20%			80%		**5**
Supermarket						100%	**13**

Table 1. classification

which is carried out by experts simply because they are not able to adjust as many fittings as the evolutionary algorithm can since an expert can only have ten appointments per patient in the space of a year. As a result, the experts need to make the most accurate estimations they possibly can in order to improve the hearing capabilities of their patients.

4. Experiments

This section contains two parts. The first part deals with the first experiments devoted to the classification of the sound environments and the second part concerns the cochlear implant fitting using IEA.

4.1 Experiments for classification of sound environments

The aim is to create a class for a specific environment, by using a collection of *.wav* files as input. The set of the sounds chosen is part of the real patient's environments. When the patient is in a new environment, he uses the sound sampler and records a sample of this environment. A .wav file is imported and chopped into 2^{14} micro-samples. When clicking on compute, each of the mini-samples is associated with the family that matches the sample best. A ratio is then displayed thus presenting the number of samples that correspond to each family, and the results are displayed in a bar-chart. The bar-chart discloses the matching family with a certain confidence. For example, if 80% of the micro-sample are classified in class S1, then the sample will be classified as class S1 with a confidence of 80%. For each family, available *.wav files have been chopped into minisamples of 2^{14} points.

Experiments were conducted with 6 sound families. 75% of the minisamples chosen randomly are used for the learning set, and 25% for the test set. The results are presented in Table 1:All samples of Car-radio, Bird, School-yard, and Supermarket environments have been correctly classified. For the Crossroad and Lawnmower environments, only 84% and 80% of the

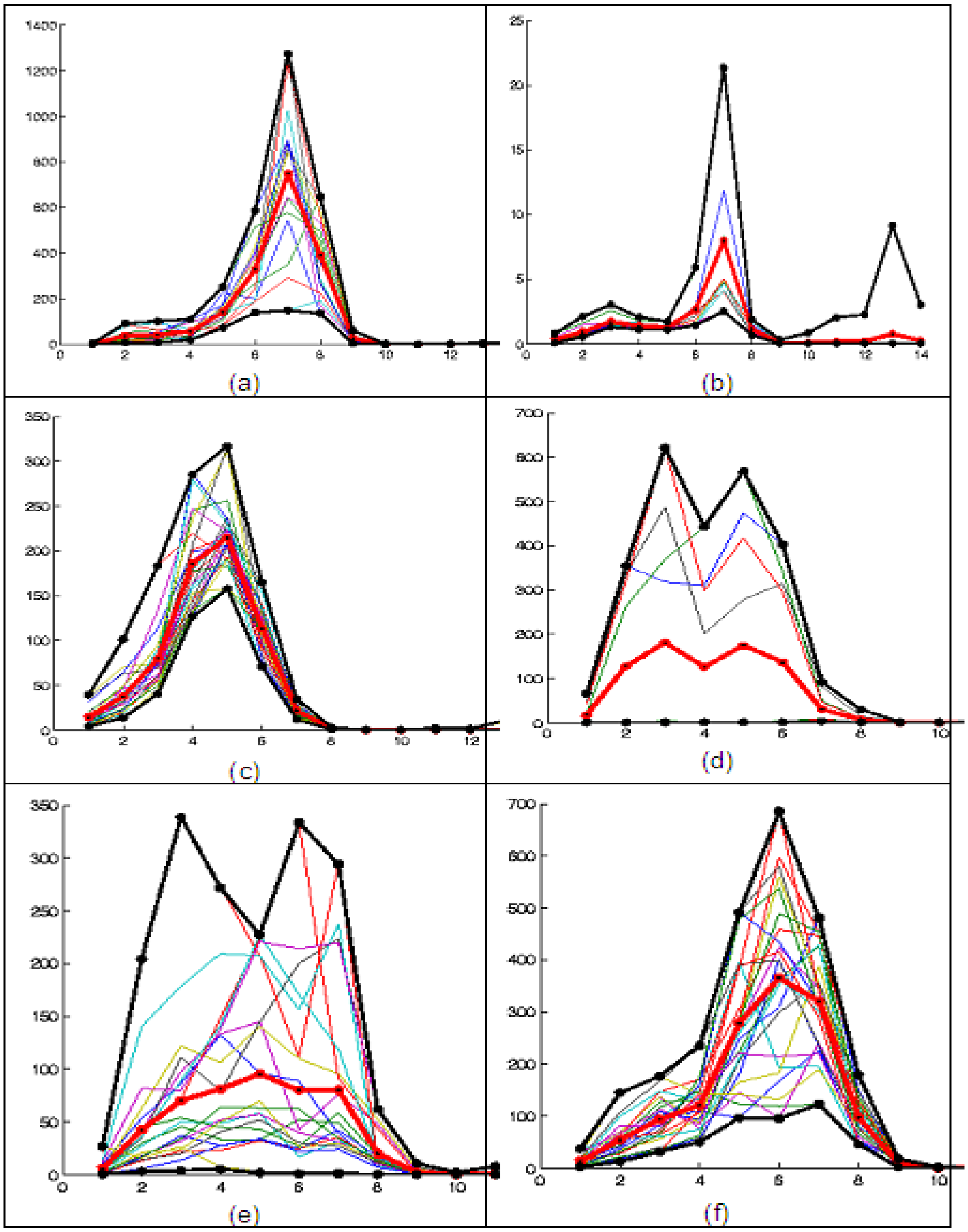

Figure 5. Set of values of the energy for each frequency (thin lines), envelope and mean criterion (thick lines) for the different sound environments (abscissa: frequency, ordinate: energy). (a): “Car-radio”. (b): “Birds”. (c): “Supermarket”. (d): “Crossroad” (e): “School-yard”. (f): “Lawn mower”

samples have been correctly identified (on the 13 Crossroad test samples, one is identified as a Supermarket environment and another one as a lawn-mower, and on the lawn-mower, one out of 5 samples is classified as being a crossroad).

4.2 CI parameter fitting with the interactive EA

For a given patient, the working session starts with the psychophysical test with an expert who determines the minimum (T) and the maximum (C) intensity values for each electrode. Then, he evaluates the patient’s hearing by using the best fittings available for a cochlear implant and sets a note as a reference point, which allows the comparison with the fittings provided by the IEA.

The proposed IEA was tested on 45 patients, which have provided about 4700 different parameter fittings. Actually, during

Electrode	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T	6	6.5	6.5	9	9	9	8	8	8	0	0	0	7	6	5
C	9.5	13	13	18	20	21.5	21.5	18	16.5	0	0	0	12	10	9

Table 2. Minimum and maximum intensity (C and T values) for each electrode

a working session with a patient, between 6 and 15 different runs of the IEA could be processed, according to the age, fatigue or availability of the patient. Note that a run of the IEA involved approximately 15 fittings (i.e. the number of generations). 66% of the whole proposed fittings have provided a better evaluation than the current IC fitting.

We detail in the following the results obtained with the "best" patient. The C and T values of electrodes 10, 11 and 12 of his CI equal zero because the auditory neuron face has apparently been damaged (he does not hear anything whatever intensity is applied to these electrodes). Table 2 shows the different values of C and T for all the electrodes and the CI expert's fitting evaluation mark is equal to 48.5.

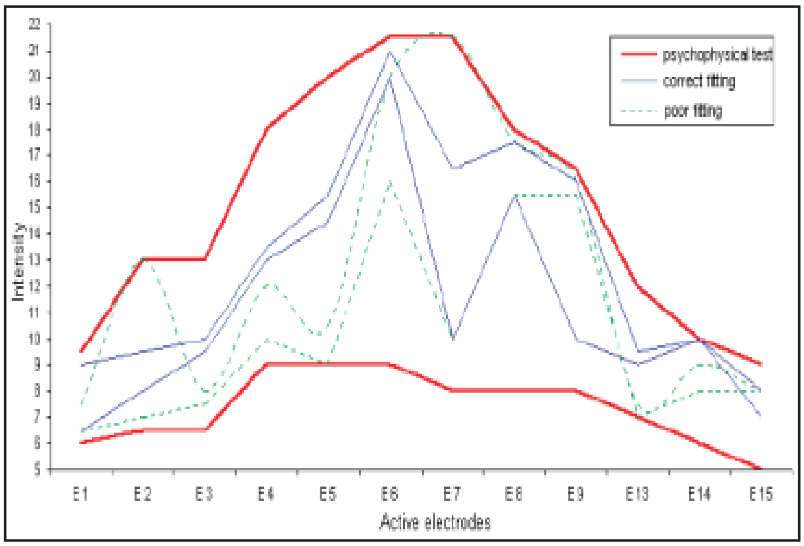

Figure 6.T and C values of the best and worst fittings. The dark lines refer to the psychophysical test. The dotted lines refer to the T and C values of the worst fitting, and the curves which are made up of a thin line refer to the best fitting (with a mark of 91.5)

169 tests were conducted. 76 % of the tests realized with the IEA have provided a mark superior to 48,5. The average time of a fitting and its evaluation was approximately of 2 minutes, with the practitioner it was approximately of 20 minutes i.e. 10 times longer.

Although the number of experiments (169) is not really significant, the best results seem to be obtained with the following parameters of the IEA:

- Population: 3 or 4 individuals.

- Number of children created by generation: 3 or 4.

- Selection mode: tournament.

- Mutation rate: 0.1.

- No elitism to avoid a premature convergence;

Values of 91 and 91.5 were obtained at the end of 2 different runs. The patient was tired but extremely satisfied and surprised by such results. The values of T and C of the best and worst fitting are presented on the figure 6. We observe that the best fitting is obtained when the IEA minimizes the information sent to electrodes 3, 4, 5, 6, 12, 14 and 15. Only electrodes 1, 7, 8 and 9 are activated. The IEA brings to light the determining electrodes in the regulation. Several issues therefore arise:

- If the difference between *T* and *C* is minimized, is it therefore necessary to deselect the electrode again?
- Can there be a problem of interference between the electrodes?
- Can the problem be combinatorial?

5. Conclusion and perspectives

The work presented in this paper proposes an automatic fitting method by using an interactive Evolutionary Algorithm. The second main contribution concerns the sound environment management. Actually, the patient's real sound environments are classified and according to the environment surrounding him, the best corresponding fitting is setting up automatically.The experimental results with the patients are very promising. The obtained results were far better than those obtained by an expert clinician. A software program that implements the complete method is designed and is included into a PDA.

What needs now to be done for the scheme to be fully functional is to connect the PDA to the cochlear implant. If the PDA is able to classify an environment with a confidence rate greater than 50%, it selects automatically the corresponding CI fitting adapted to this sound environment and it uploads it into the CI. If, on the contrary, the confidence rate is less than 50%, the sound environment is sampled and memorized and thus it can be classified later on (which may require creating a new sound class). The study continues on this topic.

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