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Automatic infant cry analysis for the identification of qualitative features to help opportune diagnosis

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ABSTRACT

In the infant cry analysis, the identification of qualitative features is of great importance, because this provides relevant information to differentiate between normal and pathological cries, which makes important their identification. Qualitative infant cry analysis has been done until now by medical personal through visual inspection of spectrograms and by the auditory study of the cry recordings. In this way, the success of the process depends on the subjective perception of the inspector besides being a very slow task. The information extracted from the perceptive observation of the crying waves recordings is then used as a help to emit diagnosis. With the idea of helping to make the whole process easier and faster we are developing a method to automatically identify, measure and highlight selected qualitative features in infant cry recordings. The processing of this identifier starts with the automatic discovery of infant cry units, which is performed by the use of a threshold applied to the energy of the signal along with another threshold applied to eliminate inspiratory cry segments, when not needed. From all the detected cry units, the process automatically identifies melodic shape, shifts, glides and noise concentration. In this work, we present, besides a quick review of related works, and a description of the perceptive analysis to help diagnosis, the process implementation, some experiments as well as the experimental results obtained.

1. Introduction

There had been a great interest in the establishment of laws to formally describe the processes of production and perception of Infant Cry. The efforts of researchers in this sense are to show infant cry not only as an acoustic–linguistic event, but also as an indicator of the neurophysiologic status of the infant.

There are two approaches for the infant cry analysis which are the quantitative analysis and qualitative analysis. In the first one, quantitative measures are used to describe the crying wave by means of different types of acoustic features.

For instance, a quantitative description of a normal infant cry is characterized by an average fundamental frequency ($f0$) of 450 Hz and ranks between 400 Hz and 600 Hz [1–4], symmetrically overlapped harmonics and with a cry durations between 1 and 1.5 s in average [1,3,5].

Alternatively qualitative analysis is available to be used on its own or as a complement to the quantitative one. Commonly, qualitative analysis is done through spectrogram visual inspection [6–8]. The qualitative description obtained provides additional information useful for the identification of variations or similarities present in the respective pathological and normal crying waves.

Due to the lack of an automatic method, the detection of significant sound segments, called cry units, is carried out in a slow manual perceptive process, either by physicians or by infant cry analysts. The usual way is to take the spectrogram of a recorded cry wave and, by visual and auditory inspection, to determine where a cry unit starts and finishes. Part of the process consists in removing the silent or noisy intervals between consecutive cry units. The process is repeated until the end of the recording looking to keep the significant cry units.

Several qualitative features can be perceived through the visual inspection of the compacted cry wave, like; melodic shape, shifts, glides, vibratos, etc. From the perceived qualitative features, medical specialists expect to gather relevant information to allow them differentiate normal from pathological cries as to help making an opportune diagnosis if possible.

With the idea of facilitating this crucial part of the process, we developed a qualitative features identification method which can

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automatically detect infant cry units from diverse types of crying recordings. This detection is done by the application of a threshold defined on the energy of the signal and another one which is applied over the detected cry unit durations. The correct definition of the two thresholds allows to remove inspiratory cries along with either silences or noisy segments. For the identification of the melodic shape we are introducing the dodecagram method, and the use of fundamental frequency values for the identification of shifts, glides and noise concentrations.

1.1. Using qualitative features for diagnosis

Specialized literature refers to the change in the infant cry due to pathological conditions. Infant's familiars often notice these changes when the child is sick. Among the diseases and pathological conditions in which infant crying has been studied are those associated with chromosomal abnormalities (cri du chat crying, Down's syndrome), endocrine disorders (congenital hypothyroidism), metabolic disorders (hyperbilirubinemia and hypoglycemia), brain damage (encephalitis, meningitis), sudden infant death syndrome, low birth weight, prematurity, asphyxia, malnutrition, and syndrome of diseases and malformations of the orolarynxeal tract (cleft lip). Other studies have included crying of children from drug addict or alcoholic mothers, etc.

Under pathological conditions, an important purpose, besides considering the changes occurring in the normal to abnormal patterns, is to know what features or attributes, as well as which are the ranges of values in the crying that may be altered by these conditions. In general, the pathological crying is associated with the following features:

- Extreme values and unstable in pitch.
- A poor voice quality in the crying due to the dispersion of the harmonics components and their inability to sustain a harmonic tone. It supports the hypothesis that the loss of harmonic stability can be caused by a loss of control of the symmetry between the right and left vocal folds in a pathological infant.
- The melodic shape change from rising or rising–falling to falling or falling–rising or flat, as appropriate.
- Sometimes it is not possible to detect the melodics shape or the shifts, bi-phonations and glides occurring.

According to these features, the definition of the pathological crying given above, and the opinion of medical experts determined that: If a crying instance has a falling or falling–rising of melodic shape or without melodic shape, besides having shifts and glides in more than 30% of the crying units, the cry might be considered as a cry with pathological trend.

2. Related work

2.1. Describing normal and pathological cry

In the effort to establish reliable features on which to support a diagnosis, infant cry researchers, through the common perceptual inspection, have found a set of descriptive features which provide the information to make a difference between normal and pathological cries. Summarizing, some of them are listed next.

A normal or healthy infant cry is defined as:

- Cry with an average $f0$ values of 450 Hz, with range from 400 to 600 Hz [2,7,9].
- The melodic shape that prevails is rising–falling [10,11].
- In the cry wave there are more cry sounds than silences [10].

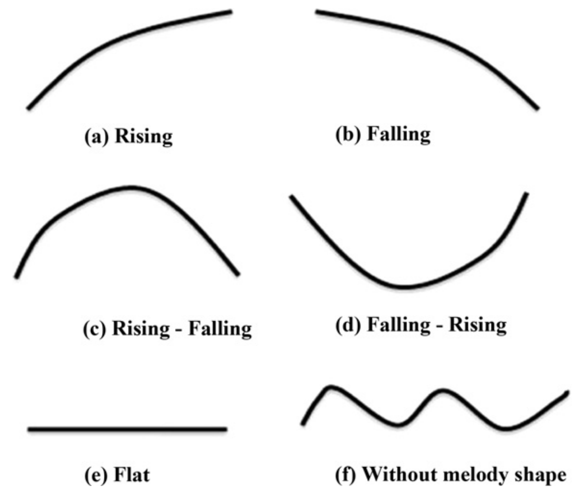

Fig. 1. Clasification of melodic shape.

The cry with a pathological tendency is defined as:

- Cries with extreme values in the $f0$.
- The melody forms that prevail are falling, falling–rising, flat and without melodic form.
- Glides and shifts happens the most.

2.2. Qualitative features

- Melodic shape is the overall melody form an infant cry wave seems to take after observing the fundamental frequency behaviour from the compacted cry wave. In general, the melodic shape (Fig. 1) can be classified as: rising, falling, rising–falling, falling–rising, flat and without melodic shape.
- *Shift or abrupt movement of the pitch*: it is a sudden change or movement of ascends or descends in the $f0$ between 100 Hz and 600 Hz within 0.1 s (Fig. 2(a)).
- *Glide*: it is a very rapid change or movement of ascends or descends in the $f0$ of at least 600 Hz within 0.1 s (Fig. 2(b)).

  The Figs. 1 and 2(a) and (b) are shown without scale or units because they are only used to illustrate the general shape a crying wave may take or the drastic raising or falling change occurring in an observed wave.
- *Noise concentration*: cry with an audible energy peak, usually from 2000 Hz to 2500 Hz within each phonatory expression (Fig. 3).

2.3. Cry units detection

As in speech, where the initial and final points of a word are located, the objective in cry unit detection is to find the initial and final points of a cry unit. As words, cry segments have higher energy than unvoiced segments; indeed cry segments have four times more energy than unvoiced segments [7].

The cry unit is defined by one segment of significative cry. The cry unit for this work is defined by two parameters: $\epsilon >$ threshold

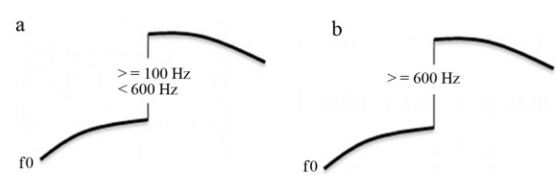

Fig. 2. Illustrating the shift(a) and glide(b) qualitatives features.

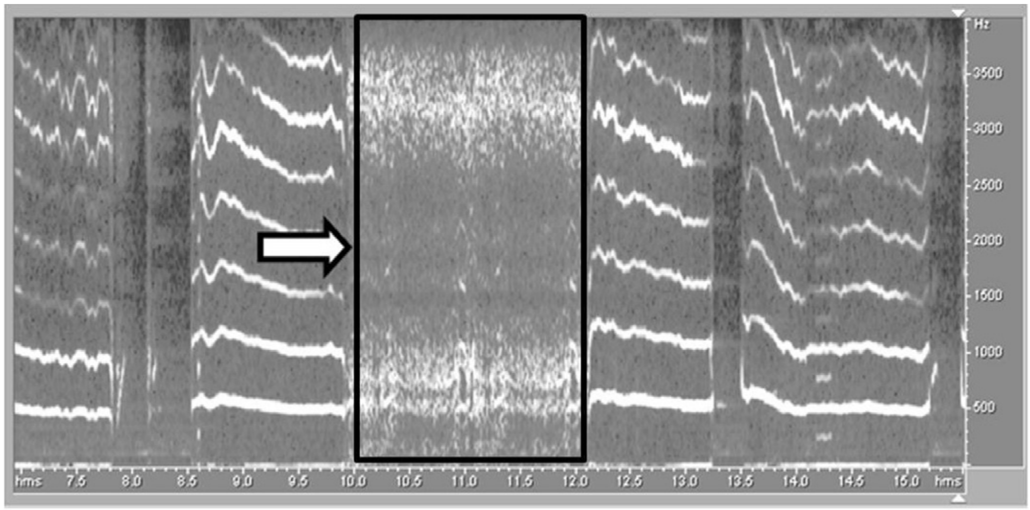

Fig. 3. Noise concentration visualized in the spectrogram.

and $\delta > 200$ ms, where ϵ determines the height and δ determines the width of cry unit.

Based on this information we analyze the energy content in a signal by applying the short-time energy function, which is used to differentiate loud segments from the silent ones. The short-time energy (STE) function of an audio signal is defined as:

$$E_n = \frac{1}{N}\sum_{m}[x(m) \times w(n-m)]^2 \tag{1}$$

where $x(m)$ is the discrete time audio signal, n is the time index of the short-time energy, and $w(m)$ is a rectangle window, whose width (in this work is 50 ms) is expressed by the following equation.

$$w(n) = \begin{cases} 1, & 0 \le n \le N-1 \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

2.4. Drawing the melodic shape

An inspiring method to visualize melodies in infant cries is called the Five Line Method (FLM). Proposed in [12], it is based on a notation similar to the musical pentagram, but applying a logarithmical scale to the frequency values and which are fixed to each of the five lines. The fundamental frequency was obtained with the Smoothed Spectrum Method, which was developed especially for the fundamental frequency detection of the infant cry [13]. Fig. 4 shows some melodic shapes obtained by the FLM. The fundamental frequency of each shape is extracted from the spectrogram, before being plotted in the pentagram.

The authors of the method FLM determined that the six categories previously established by Schönweilwer [14] covered only 70% of the potential melodic shapes. They got to this conclusion after observing the form of 580 melodies in many of which they observed more complex forms. Their method describes melodies by means of elemental forms: rising (+1), flat (0) and falling (−1)

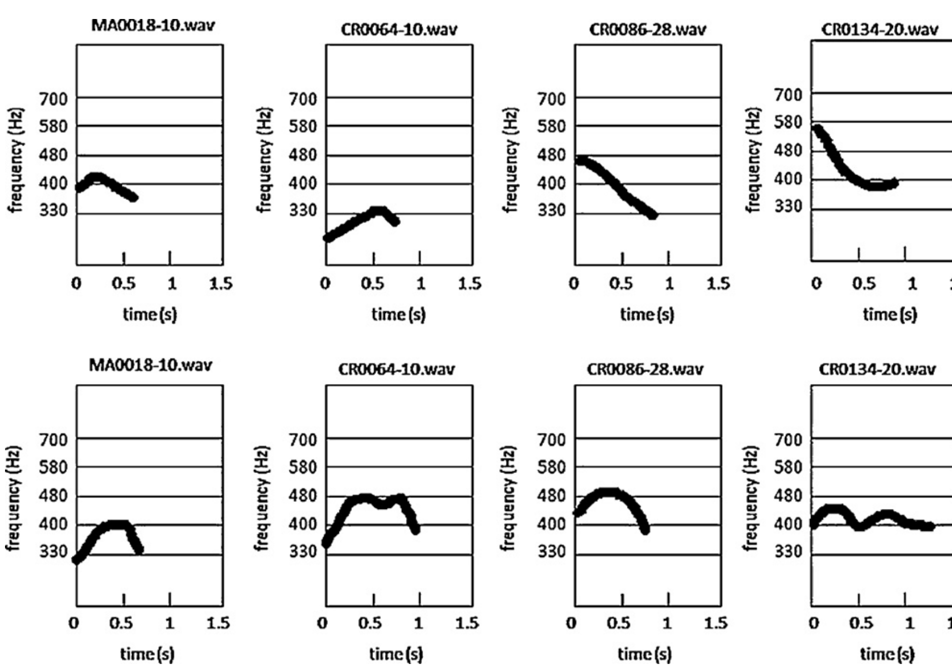

Fig. 4. Some melodies visualized with the FLM.

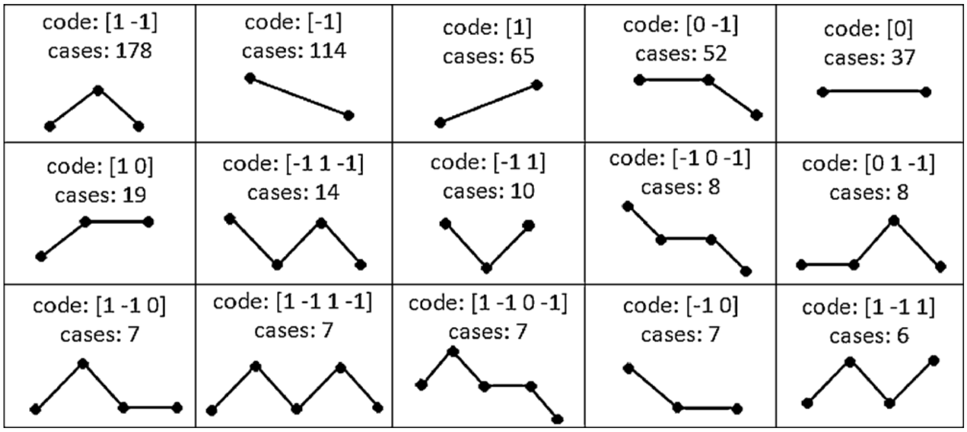

Fig. 5. Main categories found with the FLM.

and the categories are defined by the order of these values. All the melodies can be described as a combination of these elemental forms. For instance a melody of rising–falling type, is a combination of the rising form (1) and falling (−1), in this way, this type of melodies where classified as belonging to the category (1, − 1). At the end, 39 categories were established, 20 of them include 93% of the 580 analyzed melodies. The distribution of these categories and the schemas of their forms are shown in Fig. 5.

3. Proposed method

3.1. Automatic cry units detection

The cry units automatic detection is a relevant stage in the qualitative analysis, due to that qualitative features identification is performed over the cry units detected. To illustrate the way infant cry units are used, in [15] the cry units average duration is obtained, as well as the melody shape and the fundamental frequency average of the cries. In all cry recordings there are undesirable sounds, like environmental sounds and inspiratory cries, which do not provide any useful information to the analysis but they are usually present between cry units.

Inspiratory cries are produced when the infant inhales air while crying, which creates an audible sound. For qualitative features analysis these inspirations are not needed, reason why they have to be removed. There are also a variety surrounding environments and noisy devices around the crying infant during the recording process producing unwanted noises, which are noticeable also between cry units. These are sound to be removed too, as well as silence segments, to create the cry waves containing only crying sounds. The intensity and the type of the infant cry are other points to be taken in count. In the recordings we can find high-pitched or low-pitched, nasal, veiled, reedy, woody, etc. type of cries. And there are variations of the intensity due to the reduction or increase in the intensity of the cry that the infant can make during the same recording.

The process where the sound cries are detected and separated from undesirable sounds is called cry units detection, and previously was performed manually as described in [2,16]. Some software oriented to process speech has been applied to the cry units detection with no good results, because in several ways infant cry is different from speech.

Our Automatic Infant Cry Detection system was implemented in MATLAB. The first step was to identify the significant cry segments of each recording, eliminate unwanted noises and silence segments. To accomplish this task, we applied a threshold in each recording, this threshold was applied based on results of our experiments and it was proposed in [17] too, this threshold is represented by the following equation:

$$\text{Energy\_threshold} = \frac{E_n(R)}{4} \tag{3}$$

where E_n is the short-time energy function and R is the analyzed recording.

This threshold is applied to each window of the analyzed recording, in this work, the width of the window was 50 ms. Then, if the energy of the analyzed window is greater than or equal to the proposed threshold, this window is considered a cry segment.

In cry units of very short duration is not possible to identify qualitative features, like melodic shape or others of importance for physicians. For this reason, the next step was to eliminate cry units of duration of less than 200 ms. With this second step, we were able to eliminate inspiratory sounds which have a duration less than 200 ms.

The steps to follow in the proposed method are shown in Fig. 6. Fig. 6(a) shows a cry signal, in Fig. 6(b) there is a cry units detected through the energy threshold proposed, and in Fig. 6(c) the detected cry units wave after eliminating the segments of less than 200 ms is depicted.

After detecting the cry units and separating them from the recordings, several other relevant attributes are obtained. Some of them are start and finish of each cry unit, duration time, and the number of cry units in the sample, which are obtained as in [18,19]. These attributes are useful for the expert physicians as important components in subsequent analysis.

3.2. Extraction of the fundamental frequency

Once we have detected the cry units, we extract the fundamental frequency values of each cry unit, for this we used the pitch algorithm proposed by Boersma in [20], the parameters used were the following:

- *Time step*: 0.05 s (frame duration).
- *Pitch floor*: 75 (standard value), candidates below this frequency are not recruited.
- *Pitch ceiling*: 1000, candidates above this frequency are ignored.

The algorithm performs an acoustic periodicity detection on the basis of an accurate autocorrelation method. This method is more accurate, noise-resistant, and robust, than methods based on cepstrum or combs, or the original correlation methods. The reasons why other methods were developed, was the failure to recognize that to estimate a signal's short-term autocorrelation function of a windowed signal the autocorrelation function of the windowed

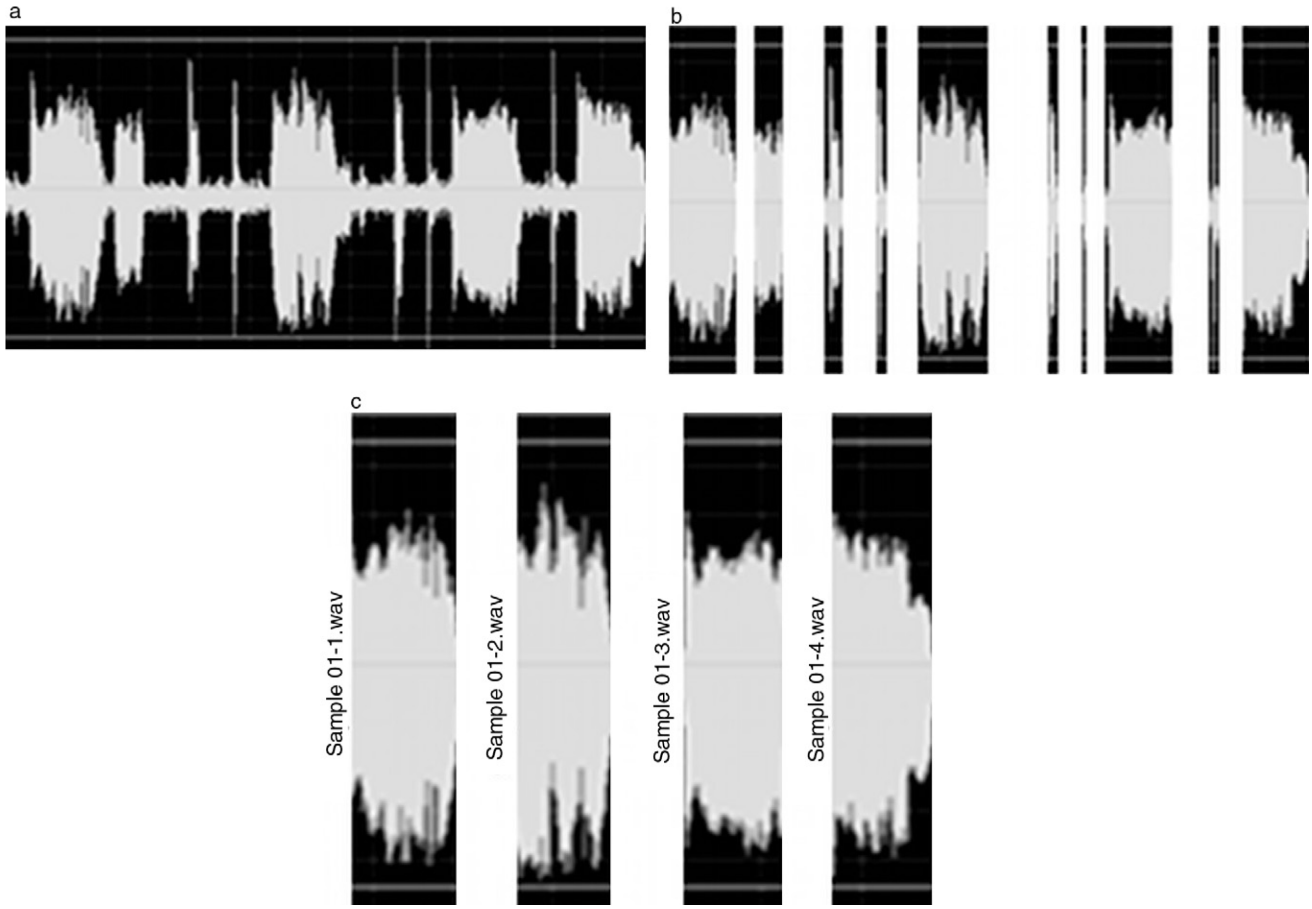

Fig. 6. Main steps in the automatic cry units detection: (a) recorded signal; (b) cry units resulting from the application of the short-time energy function threshold and (c) cry units obtained eliminating sound segments of less than 200 ms.

signal should be divided by the autocorrelation function of the window:

$$r_x(\tau) \rightleftharpoons \frac{r_{xw}(\tau)}{r_w(\tau)} \quad (4)$$

3.3. *Identifying the melodic shape*

Our proposed melodic shape identification method was implemented following the one presented in [12]. It is called the *dodecagram* method and it was implemented in MATLAB.

The fundamental frequency of each cry unit is fixed in the dodecagram. The value of the point P_i, is the value of the fundamental frequency of the first window, it can be noticed in Fig. 7 that in the second window the signal passes to the $P_i + 40$ row, in the third window the signal passes to the $P_i + 120$ row, in the next window the signal keeps in the $P_i + 120$ row, finally in the last windows the signal passes to the $P_i + 40$, $P_i - 40$ and $P_i - 120$ rows.

The next step is to encode the unit cry by the application of the following rules:

- 1 if the fundamental frequency passes to an upper row.
- 0 if the fundamental frequency stays in the same row.
- −1 if the fundamental frequency passes to a lower row.

In top of Fig. 7 the code corresponding to the cry unit in the dodecagram is shown. In the code, a number 1 corresponds to a rising of the fundamental frequency, the 0 corresponds to no meaningful changes and −1 corresponds to a falling in the fundamental frequency. With the obtained code the melodic shape and other qualitative features can be obtained by following the next steps:

- If in four consecutive windows the fundamental frequency values are 0 a concentration of noise is confirmed.
- If all the digits of the code are 0s then the melodic shape is flat.
- If there is no noise concentration and the melodic shape is not flat, then the 0s are eliminated and only the 1s and −1s are kept.
- The vectors are reduced, as shown in Fig. 8. Same consecutive digits are reduced to only one digit.

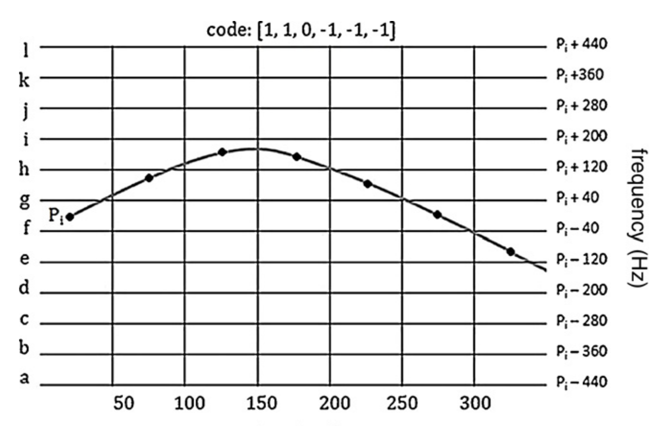

Fig. 7. Determination of a melodic shape by the use of the dodecagram method.

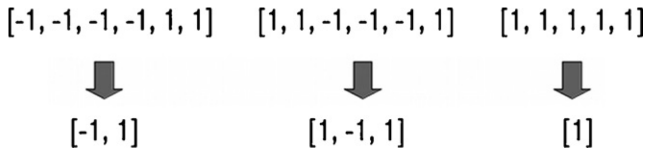

Fig. 8. Vector reduction.

- Finally the melodic shape that corresponds to the reduced vector is assigned in the following way:
  - ◊ 1: rising melody.
  - ◊ −1: falling melody.
  - ◊ 1, − 1: rising–falling melody.
  - ◊ −1, 1: falling–rising melody.
  - ◊ The vectors with size higher than 2, are considered without melodic shape.
- In order to identify the shifts, from the spectrogram, we measure the differences of the fundamental frequencies along the signal. If the difference passes 100 Hz and is less than 600 Hz, within less than 10 ms, it is considered a shift (there can be more than one in a cry unit).
- In the same way, in order to identify the glides, and also from the spectrogram, we measure the differences of the fundamental frequencies along the signal. If the difference is equal or passes the 600 Hz within less than 10 ms, it is considered a glide (there can be more than one in a cry unit).

4. Experiments and results

4.1. Detection of cry units

The proposed cry units detection method was tested over two different sets of crying samples. The first set was taken from the database called Baby Chillanto property of the Instituto Nacional de Astrofísica Óptica y Electrónica (INAOE, México), the other is a set of Cuban infant cries. The mexican infant cry corpus available is a set of 195 samples directly recorded from 112 babies by pediatricians from the Instituto Nacional de Rehabilitación-INR (Mexican Rehabilitation Institute) in Mexico City and the Instituto Nacional del Seguro Social-IMSS (Mexican Institute for Social Security) in the Puebla City. From them 123 correspond to normal cries and 72 belong to the pathological class. The same pediatricians, at the end of each recorded sample, do the class labeling. The samples were recorded with ICD-67 Sony digital recorders, and then sampled at 8000 Hz [21]. The crying corpus from Cuba, composed of 26 samples from the same number of babies, was collected at the Maternity Hospital of Santiago de Cuba with the help of the Speech Processing Group from the Universidad de Oriente (UO). For the recordings they used a cassette recorder AKAI PM-R55 and were digitized by the acquisition system PCVOX A/D [22]. The data sets were recorded under different conditions and different storage devices.

With our method we detected 182 unit cries from 20 recordings 12 s long taken from the Mexican set. And we detected 65 unit cries from the Cuban set, with 13 recordings 12 s long. The results were compared versus the results obtained by manual detection. The manual detection was performed by expert physicians [8]. Tables 1 and 2 show in detail the obtained results in the reported experiments.

4.2. Identification of qualitatives features

Our cry units identification method was tested with a labeled set, in which the labels were attached by expert physicians from the Instituto Nacional de Rehabilitación-INR (Mexican Rehabilitation Institute). These samples were taken from the Chillanto data base.

From the results in Table 3 it can be noticed that our method provides competitive results. Overall, we obtained 90.49% of accuracy in qualitative features identification against the identification made by human expert. For comparison purpose, the same set of labeled cry units was evaluated using the original method of the FLM proposed in [12].

In Table 4 we can see that the success percentage with FLM is 50.27%. Our interpretation of those results is that the main cause of the low outcome is due to the fact that fundamental frequency values from some cry units detected in our samples are above or below the values proposed for FLM, that is why many cry units are coded with 0s only.

Our method was able to correctly identify 238 qualitative features, the results were compared versus the manual identification.

Table 1
Results of the manual and automatic infant cry units detection experiments for the Mexican set.

Sample	Manual detection	Automatic detection	Accuracy	False positive	False negative
026.wav	10	10	100%	0	0
028.wav	8	8	100%	0	0
067.wav	12	12	100%	0	0
079.wav	10	10	100%	0	0
083.wav	9	9	100%	0	0
084.wav	5	5	100%	0	0
087.wav	10	9	80%	0	1
088.wav	10	10	100%	0	0
090.wav	6	6	100%	0	0
091.wav	14	14	100%	0	0
094.wav	5	5	100%	0	0
096.wav	12	12	100%	0	0
097.wav	13	13	100%	0	0
098.wav	5	5	100%	0	0
099.wav	13	13	100%	0	0
100.wav	13	13	100%	0	0
101.wav	7	7	100%	0	0
103.wav	8	8	100%	0	0
105.wav	10	9	80%	0	1
113.wav	7	9	71%	2	0
Total	187	187	96.55%	2	2

Table 2
Results of the manual and automatic infant cry units detection experiments for the Cuban set.

Sample	Manual detection	Automatic detection	Accuracy	False positive	False negative
C020812.wav	6	6	100%	0	0
C060812.wav	5	5	100%	0	0
C070812.wav	4	4	100%	0	0
C150812.wav	3	3	100%	0	0
C170812.wav	5	5	100%	0	0
C200812.wav	4	4	100%	0	0
C210812.wav	3	3	100%	0	0
C240812.wav	7	9	71%	2	0
C250812.wav	7	9	71%	2	0
C280812.wav	6	6	100%	0	0
C290812.wav	3	3	100%	0	0
C300812.wav	6	6	100%	0	0
C310812.wav	2	2	100%	0	0
Total	61	65	95.53%	4	0

Table 3
Results of the manual and automatic qualitative features identification using our proposed method on the Mexican set.

Qualitative feature	Manual identification	Automatic identification	Success percentage
Rising melody	36	35	97.22
Falling melody	36	32	88.89
Rising–falling melody	58	50	86.21
Falling–rising melody	18	16	88.89
Flat melody	34	29	85.29
Without melody shape	33	29	87.88
Shift	6	6	100.00
Glide	2	2	100.00
Noise concentration	15	12	80.00
Total			90.49

Table 4
Results of the manual and automatic qualitative features identification using the FLM method.

Qualitative feature	Manual identification	Automatic identification	Success percentage	Units out of the proposed scale
Rising melody	36	21	58.33	6
Falling melody	36	18	50.00	13
Rising–falling melody	58	34	58.62	10
Falling–rising melody	18	6	33.33	4
Flat melody	34	19	55.88	
Without melody shape	33	15	45.45	5
			50.27	

5. Conclusions

It has been proven that infant cries carry a great load of useful information, mainly related to the physical and psychological state of the baby. Based on these grounds, qualitative feature analysis from infant cry is proving its potential as a powerful non invasive tool to help the emission of opportune early diagnostics.

In the qualitative analysis. The correct detection of cry units is of vital importance for the success of the further stages of the analysis. As it was shown, with the selected thresholds, our proposed method is able to detect cry units even under noisy recordings. These established thresholds allow the elimination of silence, noise and inspiratory sounds from the crying samples. In general, our innovative proposed method will facilitate the automatic identification of qualitative features in infant cry.

In the near future we want to identify a larger set of qualitative features, like vibratos and those with a grater diagnostic force as recommended by expert physicians. We are working on a rule base with the capacity to differentiate normal from pathological cries by applying the qualitative features collected information. We like also to enlarge our databases, possibly with other international infant cry corpus, and make both qualitative and quantitative comparisons.

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