Type-2 Fuzzy Pattern Matching for Classifying Hunger and Pain Cries of Healthy Full-term Infants

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Abstract—Crying is the first way through which infants communicate with others. Various cries of infants have different meanings and origins, such as hunger, pain, etc. Therefore, the analysis of infant cries could help adults to earlier understand its needs, and diagnose its diseases. For this purpose, this paper uses the type-2 fuzzy pattern matching as a method for classifying hunger and pain cries respectively recorded from healthy full-term infants in Imam Khomeini hospital and Shahid Rajaee clinic, which are located in Noor city, Mazandaran Province, Iran. The features fed into classifier are Mel Frequency Cepstral Coefficients (MFCCs) extracted from the database. Results on one-second segments of cry signals show that type-2 fuzzy classifier has higher accuracy in comparison with Support Vector Machines (SVM) and Logistic Regression (LR) classifiers, while results on cry signals show 100% accuracy in all three classifiers.

Keywords—type-2 fuzzy sets; fuzzy pattern matching; classification; infant cry

I. INTRODUCTION

Crying is the primary language of communication for infants. Infants have no speech and are not able to use words. Hence, they express their needs and feelings (such as hunger, pain, boredom, etc) by cry [1, P. 80].

Each infant cry has special characteristics that differentiate it from its other cries. For example, time and frequency features of the pain cry are different from time and frequency features of the hunger cry[2]. Therefore, the analysis of the infant cries can make the early diagnose of its diseases and/or the early understand of its needs and its wants. It also provides an appropriate parenting.

Auditory analysis is the first technique for interpreting the infant cry. Wasz-Hockert et al [3] showed that the pain and hunger cries could be identified auditorily. Nevertheless, the auditory analysis provides only a portion of information involved in the cry signal, and is.

more dependent on the hearing ability of parents to recognize different kinds of cries [4]. Hence, more sophisticated techniques are necessary to make significant diagnostic information, and to allow the automatic recognition of the infant cries. This motivates many researchers in the world.

Studies on newborn cries were initiated by Wasz-Hockert et al in 1964 [3]. After that, many studies have been done in this area. These studies can be classified into two groups: 1) diagnosing different diseases, such as hearing disorders [5], asphyxia [6-8], Hypoxia-Related CNS Damage[6], hyperbilirubinemia [7] and so on; and 2) understanding infant needs, such as fear [8], pain[2, 4, 8-14], hunger [2, 3, 8, 13-15], sleepiness [3], wet diaper[15], and so on.

In most of these studies, Mel Frequency Cepstral Coefficients (MFCCs) have been used as features of cry signals (see [11, 12, 16-18]). Recently, Zabidi et al [18] showed that optimizing these coefficients by Particle Swarm Optimization (PSO) algorithm leads to improve the performance of Multi-Layer Perceptron classifies in the diagnosis of infant hypothyroidism.

Until now, methods which have been mostly engaged in classifying cry signals are Bayesian[10], Support Vector Machine (SVM) [13, 14, 19], Artificial Neural Network (ANN)[2, 6, 8, 12, 18, 20], Hidden Markoff Model (HMM) [11, 14, 21], and so on.

Although type-2 fuzzy sets have been successfully used in various applications such as speech processing [22-25], there are few works utilizing these sets for infant cry recognition. Santiago-Sánchez et al [7] used these sets to classify Cries of Infants under Neurological Risk. They showed the success of type-2 fuzzy sets in diagnosing diseases such as asphyxia and hyperbilirubinemia.

Hence, this paper is aimed at evaluating the performance of these sets for identifying infant needs. To this, our proposed method is the type-2 fuzzy pattern matching classifier. For evaluating the classifier, hunger and pain datasets were collected from Imam Khomeini hospital and Shahid Rajaee clinic, respectively, which are located in Noor city, Mazandaran Province, Iran.

The rest of the paper is organized as follows. Section 2 describes database. Section 3 gives an account of procedures used for preprocessing data and extracting MFCCs from the cry signals. Section 4 briefly introduces type-2 fuzzy sets and type-2 fuzzy pattern matching. Section 5 discusses classifier results based on cry segments and infants, and finally section 6 gives conclusions and suggestions for future works.
II. DATABASE DESCRIPTION

This paper uses two databases: pain and hunger. In both databases, cries were recorded by a digital Sx-750 Sony recorder placed 10 cm from the infant’s mouth. Cry signals were sampled at 16 kHz using a 16-bit analog to digital converter, and were saved in “.wav” format.

A. Pain Database

Pain database consists of 2-3 day old infants who were screened for hypothyroidism by accomplishing heel prick test. Cry recording was performed while infants were placed in a silent room at Shahid Rajaee clinic, Noor city, Mazandaran Province, Iran. Once the nurse performed heel prick test, pain cries were recorded. The total number of infants in this study is 32 consisting of 14 male infants and 18 female infants.

B. Hunger Database

Hunger database consists of 2-3 day old infants who were hospitalized beside their mother in Department of Maternity at Imam Khomeini Hospital, Noor city, Mazandaran Province, Iran. Before the mother breastfed her infant, hunger cries were recorded. The database includes 5 male infants and 14 female infants.

III. FEATURE EXTRACTION PROCEDURE

This section firstly describes a procedure for preprocessing data. This procedure is necessary to remove irrelevant information from the recorded signals, and also to provide sufficient data for further analysis. After that, Mel Frequency Cepstral Coefficients (MFCCs) were reviewed. Fig.1 shows a brief review on this section.

A. Preprocessing

Preprocessing was done in two steps. At first, silent periods were removed from the recorded signals. Then these signals were divided into one-second segments (as used in [12, 13, 17]). This leads to obtain the 121 and 339 segments from the 19 hunger and 32 pain signals, respectively. In total, we have 460 segments from 51 cry signals.

B. MFCC Analysis

MFCC is a well-known feature extraction technique that imitates the physiological characteristics of the human ear in hearing voices. This means that it linearly percepts the sounds with low frequencies and logarithmically percepts the sounds with high frequencies [16, 17]. This property makes MFCC useful for recognizing voices such as infant cries.

The steps required for MFCC extraction are as follows:

- Framing/Windowing. Infant cry is a non-stationary signal. Hence, short-time analysis must be used. To this, one-second segments of cry signals are divided into 100ms frames with 50% overlap (as used in [12]). These frames can be considered stationary, and time features of cry signals can be captured from them. Nevertheless, framing results in leakage effect in spectrum and endpoint effect in the frame. To minimize these effects, hamming windowing is used.

- Fast Fourier Transform (FFT). The second step is to take FFT from the windowed frame of the cry signal.

- Mel-scale Warping. Frequency spectrum resulted in the previous step is warped onto Mel-scale by Mel-scale filter banks. These filter banks have the frequency bands equally spaced on the Mel-scale which is defined as follows:

\[
\text{Mel} = 2595\log_{10}(1 + \frac{f}{700})
\]

in which $f$ indicates frequency.

- Logarithm and Discrete Cosine Transform (DCT). The fourth step is to take Logarithm from the warped spectrum, and after that, is to take DCT. The amplitudes of the resulting spectrum are the MFCCs.

IV. TYPE-2 PATTERN MATCHING CLASSIFIER

This section describes a method for classifying cry signals based on a type-2 fuzzy pattern matching algorithm, which requires type-2 fuzzy set-based representations. Hence, before introducing the classifier, type-2 fuzzy sets are briefly reviewed.

A. Type-2 Fuzzy Sets

Type-2 fuzzy sets (T2 FSs) were originally introduced by Zadeh [26] in 1975 as an extension to existing fuzzy sets. These sets were elaborated by Mendel and his students [27-29]. Studies have shown that T2 FSs have the capability to model more uncertainties, and the potential to outperform existing fuzzy sets.

Let $A$ be a fuzzy set represented by $\int_{x} \mu_{A}(x)/x$. A T2 FS $\tilde{A}$ is generated by keeping $x$ constant and transforming $\mu_{A}(x)$ to a secondary membership function denoted by $\mu_{\tilde{A}}(x)$. In other words, $\tilde{A}$ is obtained by blurring membership grades of $A$, and is represented by:

\[
\tilde{A} = \int_{x} \mu_{\tilde{A}}(x)/x
\]
Let $i(1, 2)$ be interval, these sets are named interval type-2 fuzzy sets (IT2 FS) and graphically displayed by a bounded region called footprint of uncertainty (FOU) (see Fig. 2). The upper and lower bounds of FOU are called upper and lower membership functions, respectively.

**B. Type-2 Fuzzy Pattern Matching**

Type-2 fuzzy pattern matching (T2 FPM) methods allocate a given sample to pre-existing classes. To this, initially, type-2 fuzzy prototypes of classes are built under the form of type-2 fuzzy sets. The classifier based on T2 FPM includes three steps as follows:

1. **Prototype Builder.** The prototypes of the classes are built from the training data. This paper uses possibility histograms for generating T2 FSs (see Fig. 3).

2. **Partial Matching.** For the $i$th element in an unknown sample $X = (x_1, ..., x_n)$, we firstly check to which element it is closer in support of the T2 FS $\tilde{P}_i$. Let the result be the $k$th element. In this case, $\pi'(x_i)$ partial matching degree of $x_i$ is computed by:

$$\pi'(x_i) = (\tilde{P}_{ik} + \tilde{P}_{ik}) / 2.$$  

3. **Global Matching.** All partial matching degrees related to $C_j$ are merged into a single degree by a matching operator as follows:

$$\pi'(X) = H(\pi'(x_1), \pi'(x_2), ..., \pi'(x_n)).$$

In this paper, the matching operator is the average of partial matching degrees. Finally, the element $X$ is assigned to class which has obtained the greater global matching degree.

**V. RESULTS**

In our work, the proposed classifier utilizes 12 and 16 MFCCs (with 20 filter banks), which are extracted from 460 one-second segments of cry signals. Since each segment is divided into 100ms frames, the number of feature vectors per a segment is 19. The average of these 19 vectors is considered as a feature vector for each segment. Then, these features are applied to the classifier. The performance of the classifier is compared with a Logistic Regression (LR) classifier and a linear SVM classifier with RBF kernel. To evaluate all three classifiers, 10 fold cross validation method is applied.

In this paper, the classification accuracy is obtained in two cases. In the first case, the accuracy is calculated by taking the number of correctly classified segments, and dividing it by the total number of segments in the test data. Results are shown in TABLE I. As can be seen, T2 FPM classifier outperforms two other classifiers, and achieves a higher accuracy. Also, the best result is obtained from 16 MFCCs. The number 16 is the optimized number of MFCCs, which is obtained by PSO. This is shown in [31].

The second case utilizes the majority vote classification accuracy. In this case, a whole cry signal is classified by a majority vote of its segments. For example, assume that a whole cry signal is divided into seven segments, and four segments are assigned to the pain class. Hence, the majority vote is the pain class. This procedure is performed for 51 cry signals. The results are shown in TABLE 2. As can be seen, all classifiers achieve 100% accuracy.

From TABLES I and II, it can be concluded that the pain and hunger cries are completely separable for the whole cry signals, while there are some errors for classifying one-second segments.

**VI. CONCLUSION AND FUTURE WORKS**

This paper presents a method for diagnosing the feeling of pain and hunger in healthy full-term infants. The proposed method is to use a T2 FPM classifier utilizing MFCCs. The results suggest that the classifier is a good method for extracting more
diagnostic information from one-second segments of infant cries.

For future works, we are willing to design a classifier with type-2 fuzzy logic systems. Also, we would use another type – reduced set for computing partial matching degrees.

### REFERENCES


