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Information system for diagnosis of respiratory system diseases

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Abstract: An information system is for the diagnosis of patients with lung diseases. The main problem solved by this system is the definition of the parameters of cough fragments in the monitoring recordings using a voice recorder. The authors give the recognition criteria of recorded cough moments, audio records analysis. The results of the research are systematized. The cough recognition system can be used by the medical specialists to diagnose the condition of the patients and to monitor the process of their treatment.

1. Introduction

A cough is one of the most important symptoms of lung disease. It is also one of the causes of patient’s need for the therapy and therefore the characteristics of cough play an important role in the evaluation of the severity of the disease, the diagnosis and treatment of the patient. According to the European Respiratory Society, cough is the most common reason of outpatient treatment in one of five cases. It takes the first place among the symptoms of pre-defined respiratory pathology [1]. Coughing itself plays an important role in the protection of the lungs from foreign objects; it often reflects the state of the respiratory system.

The nature of the cough is usually determined in the diagnostic process. There are several subjective evaluation criteria of a cough severity according to which the selected effective treatment scheme may be selected. The conventional diagnostic techniques and methods of cough are, among others, the visual analogue scale, cough diaries, cough reflex sensitivity measurement. The same techniques are used as diagnostic tools to assess the potential severity of a disease.

A particular approach to the diagnosis of cough was developed and tested in 1989 in Russia. This method and the equipment named the «Tussograf IKT1» provide the patient's audio recording continuously in the recording room for 6 hours (the patient must stay at the microphone and should not leave the recording room all this time). More recent developments [2-5] are based on the monitoring by way of the audio recording and the filtering and analysis of cough events. The accuracy of these systems is remarkably high, but as a rule there are certain limitations of their use.
For example, it was pointed out [6] that a good result obtained by the authors is not a result of the whole 24-hour recording of the patient, but the result of the selected 6 sample intervals, recorded by the automated system which required presence of the recording operator constantly. Thus, this equipment may be considered as the prototype stage.

Therefore, the development of the automatic recording system of patient’s 24-hours’ daily monitoring is really important. This system should not depend on the subjective criteria; it should be used without an operator. The system also should provide a high accuracy of the coughs recording.

Formulation of the problem. The objective is the development of the information system for cough recognition of individual momentarily patient’s coughs in the long-term recording process for monitoring the patient’s condition. A miniature audio recorder is attached to a patient for day and night recording continuously each new day. A monitored person gets along during the recording, as usual. As a result the audio record contains not only the sounds of patient’s cough, but all background noise (e.g., the sound of running water, street traffic, opening doors, ambulance siren, sneezing, etc.) and naturally, the other people’s coughs. All these sounds complicate the definition of the cough of the particular patient. The recognition of each cough as an event is required to determine the amount of such events, their frequency and time.

2. Materials and methods
Information system (IS) developed by the authors provides automatic monitoring the 24-hours’ daily records of patients with lung disease for diagnostics and treatment control in a mode. Its block diagram is shown in Figure 1.

1. The process of audio signal processing is divided into four blocks, performing various functions.

Figure 1. Information system block diagram
Unit 1 makes the pretreatment of the patient’s daily sound recording. The record is copied from the recorder and converted (if necessary) to the desired input format with the required parameters, whereas a record can be played in various audio formats which should be unified. Digital format WAV was chosen as a standard format for further processing and analysis by the information system. This is an uncompressed digital audio signal based on the pulse code modulation and it does not impose any restrictions on the IS coding algorithm. Single-channel monophonic recording is used which provides correct separation of cough from noise.

Unit 2 provides identification of sounds of coughing from noise made. To do so, the sampling of fragments with duration 500 ms is made throughout the entire daily record, these segments must have a sharp peak of amplitude at the start, which corresponds to cough. Audio segment containing cough is shown in Figure 2. However, the external noise may be superimposed on the fragments of the recording. Furthermore, the authors’ experiments demonstrated that the fragments of cough of one and the same patient may vary considerably in length and amplitude. Therefore, the pretreatment of audio tracks is carried out at this stage. Filtering and cutting of high frequencies are made by Unit 2. Then the graph (of a cough) is divided into 2 parts: the positive one which is, roughly, above the x-axis and the negative one which is below the axis, their enveloping curves are drawn and fast Fourier transform is made.

Unit 3 performs the analysis and recognition of audio signals. In these experiments, the exact criteria for the selection of audio signals of cough are proposed and a number of mathematical evaluation were discussed and analyzed in order to select the one for the comparison of the recorded fragment and the reference fragment of cough (e.g., correlation coefficient method, standard deviation, variance, Bayesian estimation, interval estimation, integral evaluation, etc. were reviewed).

Pearson correlation coefficient was used in the correlation analysis, which allowed us to determine the number of cough events corresponding to a reference cough fragment. The authors analyzed a number of variants of the criteria for calculating the correlation coefficient.

1. The correlation coefficient of the audio signal’s positive part envelope and the reference after smoothing with a predetermined fixed time window. Calculation of the linear correlation coefficient is made between the two smoothed envelope graphs throughout the length of the cough event fragment and the reference one. Variable parameters are the reference, and the length of the smoothing window, compared to the time.

2. The correlation coefficient of the positive signal amplitude’s envelope with the reference signal with time scaling. This criterion applies to the positive part of the smoothed envelopes of the two signals (reference cough record and the sound in the test interval) to align them in time. The scaling of the current track time is made. The scale is calculated from the start point of the cough to its maximum amplitude. Then the correlation coefficient is calculated between the scaled signal’s envelope curve and the reference curve. This parameter minimizes the effect of different stage length of the cough moment and the reference one in the test recording.

3. The correlation coefficient between the spectral envelopes at the frequency with the maximum signal amplitude. In this case, a spectrum of the current track and the reference signal are drawn, the maximum amplitude is found and the correlation coefficient is calculated. Calculations can be made for different reference signals, different time lengths of the smoothing window, different lengths of the analyzed envelope segments by time and a different window width for fast Fourier transform.

4. The average value for the characteristic spectrogram fragments can also be used to compare the reference signal and the current track. If the difference between the reference and the selected fragment does not exceed predetermined recording threshold, then the current fragment is a cough event.
record, otherwise it is not. Variable parameters in this case are the reference record, length of the window in which the spectrogram is formed by the fast Fourier transform, the coordinates of the window’s time boundaries, the coordinates of the window’s frequency boundaries.

5. The integrated error between the positive and negative envelopes can be used for the verification of the signal’s symmetry to the x-axis. In this case, the smoothed envelopes are formed for both the positive and the negative parts of the analyzed audio fragment. Then the integral error between the envelopes is calculated to determine the symmetry of the signal. The cough is characterized, as a rule, by its symmetrical waveform, whereas for noise, it is asymmetrical in most cases. Variable parameter is the width of the smoothing window fixed by time marks.

6. Spectral analysis is another tool for identification of a cough event, which is actually the coughing moment. The best results were obtained with the MUSIC (MUltipleSIgnalClassification) method [7], which allows carrying out a spectral analysis of sound segments that are the sum of several sine waves. Simultaneously, the frequencies and the levels (amplitudes and power) of the harmonic components can be determined.

The set of different criteria for the selection of cough fragments proposed by the authors reflects the main distinctions which were identified in the preliminary analysis of the experimental data (viz., the audio records), making it possible to separate the significant fragments of a record from noise by way of cutoff of interfering noise records after their recognition.

Final result of the processing of the monitoring records in the information system is based on the recognition results formulated as the conclusions that are obtained by the analysis of the rules which are, in turn, have been developed on the basis of fuzzy logic [8]. These rules can be generated basing on one or several parameters. For example, a rule based on a single parameter can be shown:

\[
\begin{align*}
\text{IF} & \quad \text{parameter1} \geq \text{const1}, \quad \text{THEN} \quad \text{it\_may\_be\_cough,} \\
\text{IF} & \quad \text{parameter1} \leq \text{const2}, \quad \text{THEN} \quad \text{it\_may\_be\_cough,} \\
\text{IF} & \quad \text{const1} \leq \text{parameter1} \leq \text{const2}, \quad \text{THEN} \quad \text{it\_may\_be\_cough,}
\end{align*}
\]

where \( \text{parameter1} \) is one of the above criteria; \( \text{const1}, \text{const2} \) are limiting values of the parameters.

Applying the inference rules, one can use various criteria, both in the individual key, and in combination with each other. The probability of processing the sound recording without additional parameters is very limited as a rule. At the same time, the method utilizing the mathematical analytical model for the raw experimental data makes it possible to see more details of the research and to compare the interaction of various parameters of inference rules and that of the sound signals recognition in general. The main condition for the effectiveness of a computational experiment is the adequacy of the mathematical model used in the recognition process of signals corresponding strictly to cough. The result was determined on the basis of the final rule combining all criteria mentioned above. Thus, in this research it was suggested that the current fragment of an audio record shall be recognized as cough if all applied fuzzy logic rules give the result: \text{it\_may\_be\_cough}.

Unit 4 (Fig. 1) provides visualization of both the calculations and the processing results of the experimental data. In Unit 4, the statistics records are also stored giving the opportunity to analyze in detail the researched parameters (viz., time, frequency, amplitude of the signal), and as the view of sound fragments graphs, the enveloping curves and spectrograms.

3. Experiment

The analysis of monitoring records of three patients was made. Initial audio records were preprocessed (filtered) and then converted into a single-channel (mono) audio record in the *.wav format. To provide the efficient result of audio signal recognition, the analysis of recording parameters of cough was made to determine the reliability of their isolation from noise with minimum resources. Experimental results demonstrated that reliable cough detection can be achieved using the 44.1 kHz ADPCM mode and 4 bit quantization.

Cough identification using all the above mentioned criteria described above was made; to analyze the results, first, it was made in two directions:
- total number of correctly recognized coughs, of all coughs (%);
Table 1 shows the experimental results of patient's sound records processing with all the criteria listed above applying different arguments. Numbers in Table 1 refer to the numbers of the criteria descriptions below. A number of criteria were tested with different variants of the original data. Frequently changing criteria in the arguments are expressed as the window border size. It can be either wide, containing the whole range of an audio segment, or its 2/3 part, or narrow, just 1/3 of the range of an audio segment or even less. Table 1 shows the variants of data recognition where there are 50% and more percent of correctly identified cough fragments.

Table 1. Experimental results. Effect of cough/noise recognition criteria.

| №  | Criteria                                                                 | Variants of criteria calculations | Correctly recognized coughs of the total number of cough events, % | Erroneously recognized coughs of the total number of cough events, % |
|----|--------------------------------------------------------------------------|----------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 1  | Positive envelope correlation criterion                                   | 1                                | 67                                                            | 71                                                            |
| 2  | Positive envelope correlation coefficient of the scaled audio fragment     | 2                                | 98                                                            | 43                                                            |
| 3  | Correlation coefficient of the spectrum envelopes at the frequency with maximum signal amplitude (with narrow time boundaries) | 3a                               | 67                                                            | 36                                                            |
| 4  | Correlation coefficient of the spectrum envelopes at the frequency with maximum signal amplitude (with wide time boundaries) | 3b                               | 78                                                            | 21                                                            |
| 5  | Correlation coefficient of the spectrum envelopes at the frequency with maximum signal amplitude (with narrow boundaries in the spectrogram window with frequency shift) | 3c                               | 89                                                            | 36                                                            |
| 6  | Correlation coefficient of the spectrum envelopes at the frequency with maximum signal amplitude (with wide boundaries in the spectrogram window with frequency shift) | 3d                               | 67                                                            | 43                                                            |
| 7  | The average of the characteristic fragments of the spectrogram (with wide window spectrogram) | 4a                               | 56                                                            | 29                                                            |
| 8  | The average of the characteristic fragments of the spectrogram (with a narrow window of spectrogram) | 4b                               | 89                                                            | 29                                                            |
| 9  | The average of the characteristic fragments of the spectrogram (with the least average value) | 4c                               | 94                                                            | 57                                                            |
| 10 | Integrated error between the positive and negative envelopes (with minimum threshold of error value) | 5a                               | 67                                                            | 29                                                            |
| 11 | Integrated error between the positive and negative envelopes (with maximum error threshold) | 5b                               | 78                                                            | 43                                                            |
| 12 | Integrated error between the positive and negative envelopes (with the average value of error threshold) | 5c                               | 78                                                            | 43                                                            |
| 13 | Spectrum analysis based on the MUSIC method                               | 6                                | 95                                                            | 15                                                            |
4. Conclusion
The analysis of the results shows that each of the following criteria alone gives a positive result and makes it possible to exclude more than half of the false recognitions of cough. If the criterion of efficiency is defined as the criterion of the most correct definition of cough and minimum false definitions with equal weighting ratios, the tested cough recognition methods can be classified as follows: the most effective cough recognition methods are Nos. 6, 3b, 4b, 3c, 2, 5a (in order of their decreasing effectiveness). Less effective methods are: 4a, 3a, 5b, 5c, 4c, 3a; however, they also can be used for calculations. It should be noted too that each parameter is effective in filtering out its own specific fragments as noise, whereas the other parameters recognize the same fragments as cough.

In addition to the analysis of the feasibility and applicability of individual criteria, the efficiency of several integrated criteria was reviewed. In this integrated case, the correct recognition of cough is improved, and the percent of false recognitions of cough (noise) is lowered. As a result, in the integrated application of several criteria in the conclusion-making rules, the cough vs. noise recognition error does not exceed 5%.

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