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AUTOMATIC UNDERSTANDING OF ACOUSTIC SPEECH SIGNAL PATHOLOGY

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In this work, parts of the research concerning a new concept of applying computer technique in pathological speech analysis have been presented. This new concept assumes that during the pathological speech analysis we are not aiming neither at the establishing of such or other signal parameters nor at the trying to classify them, but we tend to understand automatically the causes of deformation, which can be observed in the considered signal. Therefore the concept presented postulates the replacing the well known process of the pathological speech acoustic signal recognition by a more advanced method of analysis, which means a confrontation of the features, which are revealed in the signal during its transformation with features that could be expected basing on the knowledge gathered in the system concerning pathological factors deforming the true form of the signal. In the meaning of the term "automated understanding", this denotes a signal analysis of a deformed speech, which is oriented towards revealing the sources of the observed signal distortions, and not towards bare analysis of their patterns and diagnostic deduction based on their typology. In the work the basic elements of the proposed method are presented. Examples showing its essence were derived basing on the selected larynx pathology analysis.

Keywords: speech analysis, speech processing, speech recognition, pathological speech, automatic diagnostics, computer based therapy monitoring, biomedical engineering.

1. Introduction

The methods of acoustic signal analysis and transformation, using computer techniques and treated as highly advanced techniques, are presently techniques which are routinely applied to medical diagnosis and therapy. This fact does not mean that those problems are not any more an attractive area of scientific research. In many issues concerning medical diagnosis, as well as in the planning and monitoring of speech organs or organs connected with speech therapy and rehabilitation, it is necessary to evaluate qualitative features of the acoustic signal of the deformed speech. The tasks concerning the pathological speech signal analysis and recognition, which characterizes the selected form of pathology, are extremely difficult. This difficulty results from the fact that speech organ pathology (which is supposed to be recognized), generating various forms of speech signal distortion, are quite often difficult to foreseen and very difficult to become recognized in a real, registered speech signal of the examined patient. The correlation between phonetic and acoustic phenomena, which are observed in the time or frequency range of speech sounds representation, generally correlate weakly with the morphological or patho-physiological features of the deformed speech signal generator. It happens that minor pathological elements (e.g. an occlusion defect) is strongly manifested in the speech signal, while very serious pathological changes (e.g. tumors) give only a weak and hardly readable picture of the speech disturbances. Therefore it is very difficult to diagnose the condition and pathological changes of the voice tract using a speech signal [1], in spite of the existence of multiple examples of successful automated speech recognition in the semantic or personal aspect. There is no simple way to transfer the experience related to diagnosis of a technological system, because the problems of pathological speech diagnosis are specific to the fact that for such tasks it is very difficult to find an appropriate rule for the preliminary signal analysis. Moreover, it is also difficult, and sometimes even impossible, to indicate a proper recognition algorithm for the pathological speech signal [2]. This follows from the fact that during the identification of the voice tract pathological states basing on the generated deformed speech, it is necessary to resort to highly specialized (atypical) methods, both for the signal parameterization as well as for its categorization and classification.

A typical scheme for the registration and classification of an acoustic speech signal with one way flow of information is presented in Fig. 1.

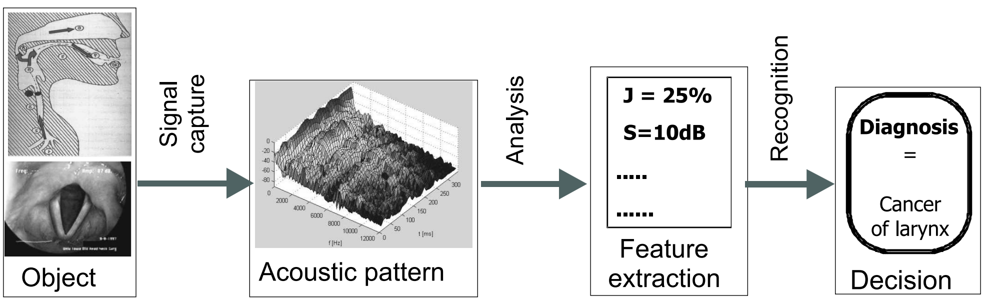

Fig. 1. Scheme for classical recognition – one-way information flow.

On the basis of the discussed problems concerning the analysis of speech pathology forms and causes, it appears that it is impossible to apply generally known methods of automatic signal recognition. Another approach is suggested – an approach based on the concept of automatic understanding [3–8]. Generally speaking, the understanding differs from recognition by the fact that it is strongly **based on the knowledge.** Therefore "automatic understanding" means such a deformed speech signal analysis, which aims at determining the causes of the signal forms based on diagnostic results resulting from their typology.

In the tasks of signal understanding, the information flow is a two-way one (in contrast to the classical recognition system), as two streams of information are compared, the streams coming from the basis of the knowledge about the pathological speech signal and the real signal of the deformed speech. The scheme of such an approach is presented in the Fig. 2.

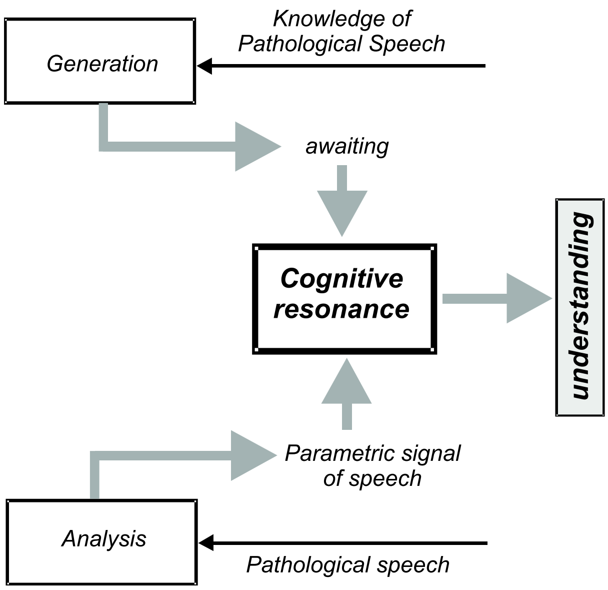

Fig. 2. Two-way information flow during an attempt of speech pathology understanding.

It is assumed that this system is equipped with a knowledge base in a form of pathological speech signal patterns together with associations linking these patterns with particular voice channel pathologies.

2. Necessity to introduce the concept of signal understanding

It happens sometimes that minor pathological elements (e.g. occlusion defect) strongly manifest in the speech signal, while very serious pathological changes (e.g. tumors) give only a weak and hardly readable picture of speech disturbances. There is no simple way to transfer the experience related to diagnosis of a technological system, because the problems of pathological speech diagnosis are specific to the fact that for such tasks it is very difficult to find an appropriate rule for the preliminary signal analysis. Moreover, it is also difficult, and sometimes even impossible, to indicate a proper recognition algorithm for the pathological speech signal [2].

The well known and simple concepts of recognition of speech sound patterns fulfill perfectly their role in a routine recognizing the statement content or in the speaker's verification. However, they do not fulfill well the expectations concerning various forms of speech pathologies. The reason is the changeability and diversity of a pathological speech acoustic signal. This concerns certainly both the normal and pathological speech [10].

Every person speaks in a different way, by different (from the point of view of the content or speech speed) pronunciations, and even the same person reveals various speech phonetic-acoustic features. The same words coming from the same person, but recorded, for example, on different days, can be strongly distinct.

It is almost a rule that various samples of a normal speech signal exhibit a bigger variability of the measured acoustic parameters than the measurable differences of the same parameter between normal speech samples and registered samples of a speech that is evidently a pathological speech.

This is the reason that the creation of an appropriate features space, in which it would be possible to make a representative description, and then an effective differentiation of individual speech pathology forms meets with very large difficulties.

All the mentioned above facts lead to a conclusion that one cannot limit to a model of pathological speech signal recognition in a space based on their features set, but for every case the **understanding** of the origins of phonetic or acoustic phenomena is required.

3. Basis of the suggested concept

The bases of understanding a pathological speech signal were derived from the works conducted by the prof. R. Tadeusiewicz's team and concerning among other things the application of this concept (automatic understanding of a picture) in the medical pictures analysis [4, 9]. A solution of the arising problems can be searched by modeling human cognitive processes. The human perception is always an occurrence of two information streams: one flowing from the inside (generated by the possessed knowledge) and another one flowing from the outside (as an information stream from the sense organs). Comparing these two streams of information by an appropriate manipulation of the observed phenomenon internal model allows a correct perception and steady recognition. Choosing one of many possessed recognizable phenomena and process models as those, to which it is possible to adjust new sense experiences most accurately the human brain performs a categorization of this sensation. On the other hand, by the adaptation and modifications of this model necessary for achieving a required matching with the perceived sensory experience, the brain indirectly measures the "distance" of the actual sensory experience from its standard model. This last process, in particular, seems to be very interesting from the point of view of the tasks of evaluation the pathological speech signal deformation degree. The concept of basing the pathological speech automatic diagnosis system on the presented scheme of a "cognitive resonance" means that the diagnostic system must be equipped with an internal model of a signal generator. Such a model is based on the knowledge of a speech signal and on the ways of its arising both under the normal conditions, as well as under pathological ones. The parameters of this model are modified by the process of the input signal analysis. A general concept of the methodology presented above is shown in Fig. 3.

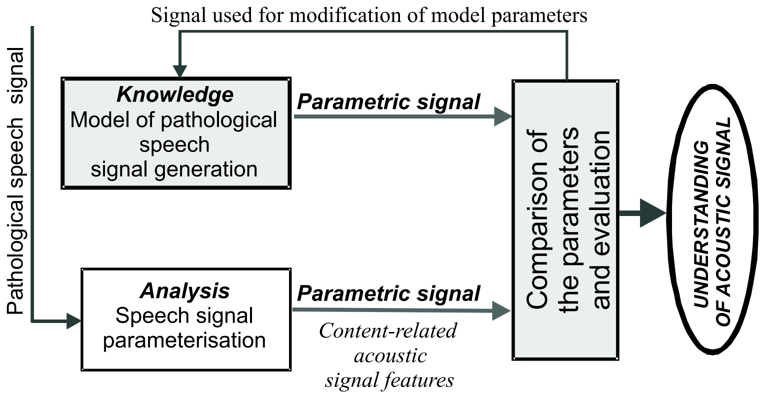

Fig. 3. Simplified model of the proposed concept.

The expectations are characterized by some conditions. The conditions describe the characteristics of the specific speech signal assuming that the features of this signal's generator are equal to one of the variations of its medical interpretation of the structure and function of the deformation. The presented above general scheme of the described method, concerning automatic pathological speech signal understanding, assumes that the knowledge of a signal, incorporated in the selected appropriately parameters, is confronted with the information included in the real pathological speech signal. In the method suggested, this is not just a sole measurement of particular speech signal parameters, and on their basis a better or worse recognizing of the forms of its generator's pathology. In this approach, causal relationships are used that make the basis of various forms of the speech signal deformations. A comparison of the knowledge of a speech signal with its real signal is performed on the basis of selected parameters of the acoustic pathological speech signal. The result of this comparison, the model is adjusted to the reality.

The development of this concept results in the possessing of many hypothetical models of the deformed signal generation. These models result from the knowledge of the well known forms of speech pathology. The realization of this concept is presented in Fig. 4.

In this concept, the process of agreeing on the recorded signal parameters coming from the examined patient and signals coming from internal generators, firstly leads to selecting of a generator for which the strongest cognitive resonance occurs. In the

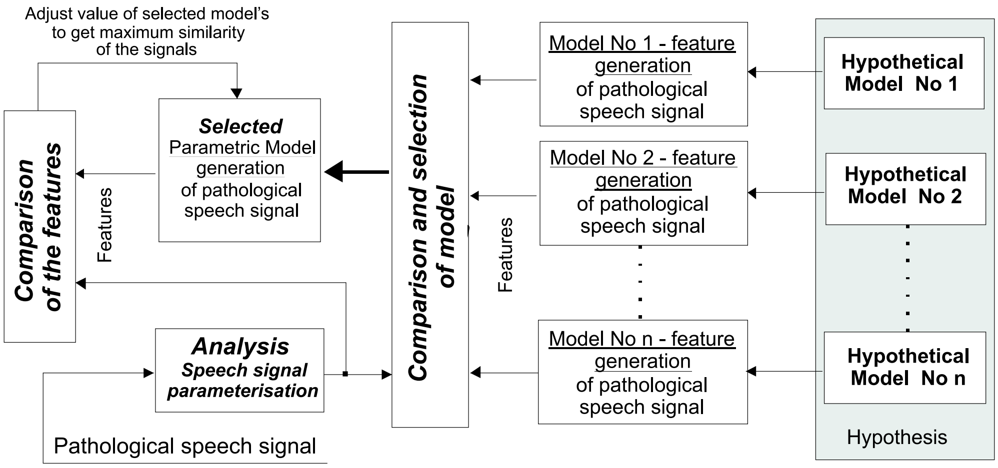

Fig. 4. Block diagram of the concept basing on hypothetical models of signal generation.

process of automatic understanding of the origins of the speech deformation this corresponds to the stage of establishing the diagnostic hypothesis. In the next stage of the model perception process of adjusting the internal generator model parameters, the aim of adjusting it to the pathological speech signal parameters causes the setting a more precise diagnostic hypothesis.

4. Research samples

The studies of speech articulation have been carried out for persons treated by ENT surgery. The final acoustic material has been collected from 175 people divided into two groups:

A reference group (standard group), 25 people with correct pronunciation.

A group of patients (150 patients) treated by the following surgery methods:
intubations (including prolong intubations) (20 patients),
resection of the septum of the nose and paranasal sinuses surgery (30 patients),
removing of inflammation polyps of the larynx (25 patients),
partial surgery of the larynx (75 patients).

The registration of acoustic signals has been carried out in an anechoic chamber, where the time dependence of the acoustic pressure of a signal during the pronunciation has been registered by a magnetic digital tape recorder.

Both the patients and the people of the reference group pronounced the same text (three times), which consisted of vowels, words containing vowels, and a test sentence. The set of words has been chosen on the acoustic basis (the words contain all the phonemes expected to exhibit the speech deformation resulting from the operation). Samples of speech signals recorded during reading have been examined.

5. Specificity of the problem of understanding pictures of a pathological speech acoustic signal

Presenting the method considered in this work, we recall examples of pathological speech acoustic "pictures". The most often aim of a pathological speech analysis is to conclude what deformations occurred in case of a voice channel, and in connection with it, what a probable illness process occurs that is responsible for these speech signal deformations. The recognition is not sufficient in this case. Moreover, it is not possible either to enumerate nor to describe totally all the possible forms of speech signal deformations, which are caused in the voice channel by an illness process. The most often occurring ones are those resulting from an illnesses which themselves cause various deformations of the acoustic speech signal appearing within different wavebands. Figures 5, 6 and 7 presente how the dynamic spectra (multispectrum) of acoustic pathological speech signal vary the word */ala/*, acquired from three different patients with the same illness (larynx cancer).

In the situation presented, it is obvious that every recognition attempt (including this signal into the classes determined in advance) is usually impossible. Thus it is impossible to specify exactly the pattern of a pathological speech signal generated by a specific vocal tract illnesses. However, if the causes of signal deformations (the nature of voice channel) are understood by an appropriate interpretation of acoustic speech signal parameters confronted with expectations concerning these parameters, this can be used in a support of the diagnosis process. The process concerning automatic understanding of speech signal deformation causes can be applied also in the therapy process of patients with a damaged voice channel.

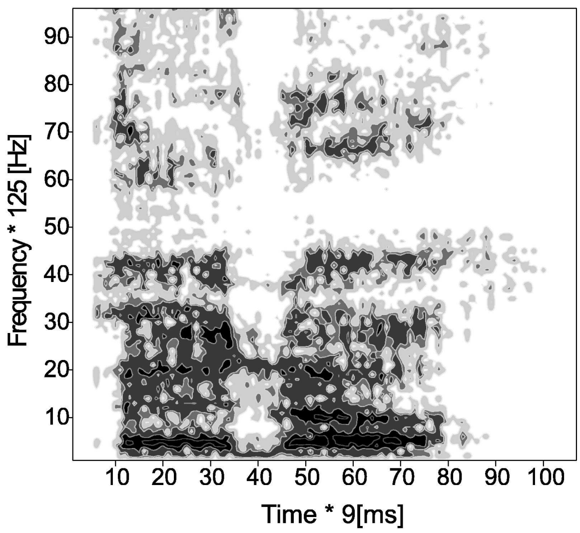

Fig. 5. Larynx cancer – patient no. 1, word */ala/*.

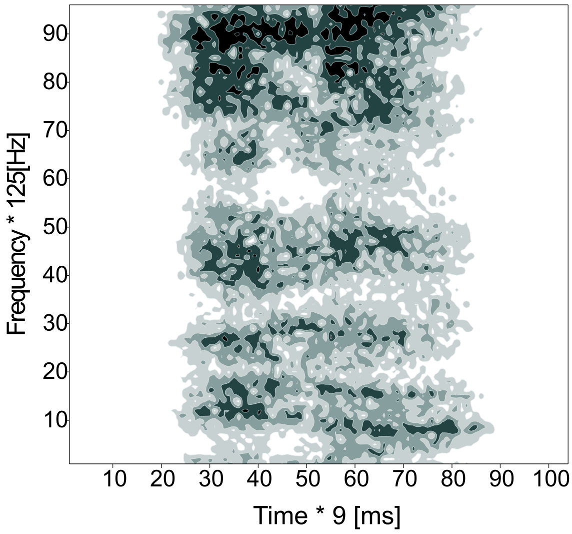

Fig. 6. Larynx cancer – patient no. 2, word /*ala*/.

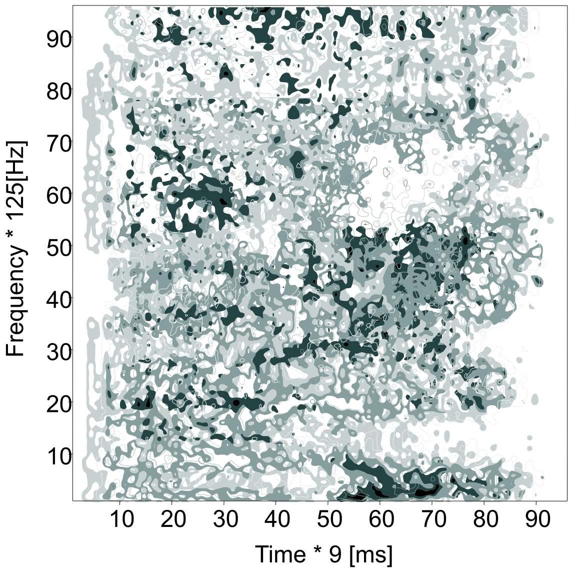

Fig. 7. Larynx cancer – patient no. 3, word /*ala*/.

6. Simulation model of selected vocal tract pathology

During the pronunciation of a particular text, a sequence of programmed articulation movements is realized, the aim of which is a proper acoustic signal formulation. This signal is created as a contribution to the whole set of articulation organs constituting a certain acoustic complex. The process of acoustic speech signal creation can be presented in a shape of a theoretical model projecting the functions performed by the individual organs. This work was restricted only to a simulating model, which enables to determine the signal spectrum on the basis of geometrical parameters of a vocal tract corresponding to speech signal articulation. Examining the model of a speech generation set, the output signal is treated as the transmitting acoustic set answer representing the voice channel of transmit $H(s)$, submitted to acting the stimulating function of larynx source as a flow function $U_g(s)$ and loaded with the lips impedance radiance $Z_r(s)$ [11, 12]. A simplified scheme of the speech organ is presented in Fig. 8.

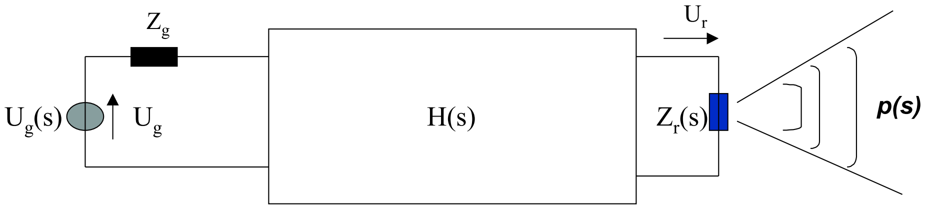

Fig. 8. Substitute scheme of the speech organ for speech sounds articulation of larynx evocation [14].

In the simulation model, three fundamental blocks were selected conventionally:

- the larynx source (source of acoustic wave),
- the voice channel transmittance (articulative apparatus),
- the radiance impedance of the mouth $Z_r(s)$.

In the scheme, the following quantities were determined:

$P(s)$ – acoustic pressure, $U_g(s)$ – evocation function of larynx source, $Z_g(s)$ – internal impedance of larynx source, $H(s)$ – voice track transmittance, $Z_r(s)$ – radiance impedance of mouth, U_g – volume speed of air in the glottis aperture, U_r – volume speed of air in the mouth aperture.

In relation to the gathered research material represented by the samples of the pathological speech signal derived from the patients who were cured because of a larynx cancer or polyp, this work was limited to the modeling of a fragment of the voice channel, which is the larynx source.

Two models were considered; a simplified one based on the spectrum characteristics, Fig. 9.

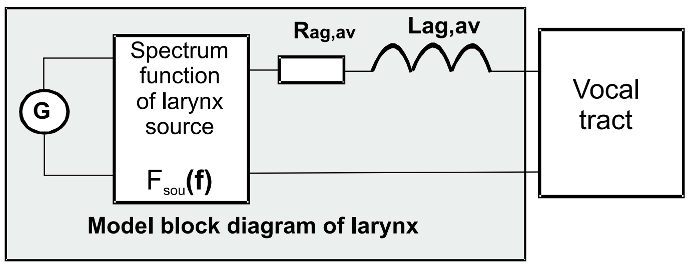

Fig. 9. Simplified substitute scheme of larynx generator.

The generator G presented in the scheme is a source of signals characterized by the following frequencies $f_0, 2f_0, 3f_0 \ldots$, where $f_0 = 1/T_0$. The amplitude of this signal is proportional to the pressure differences under and above the glottis. The spectrum function of a larynx source F_{sou} reflects a simplified characteristics of the spectrum envelope $|\mathrm{Ag}(j\omega)|$.

$$F_{\mathrm{sou}}(f) = \frac{1}{\left(\frac{f}{f_0}\right)^2}. \tag{1}$$

The acoustic resistance $R_{\mathrm{ag,\,av}}$ and the acoustic volume $L_{\mathrm{ag,\,av}}$ of the source correspond to these elements for the average value of the glottis surface intersection A_{av}.

For the purpose of this model, there was a limit in the comparison of the real pathological speech signal to that one created according to the model. The larynx defect caused by a surgical operation was investigated as a voice channel pathology. In Fig. 10, a source spectrum of the /a/ vowel is presented.

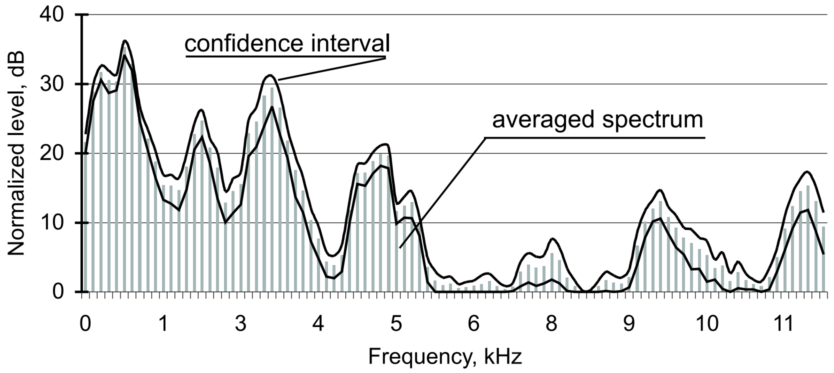

Fig. 10. Averaged spectrogram of /a/ phoneme – normal speech.

In Fig. 11, a vowel /a/ spectrum of a pathological speech is shown.

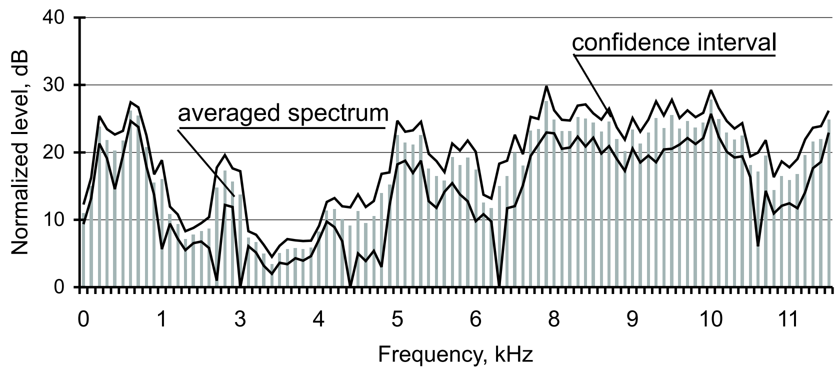

Fig. 11. Averaged spectrogram of /a/ phoneme – pathological speech.

From the studies of the corresponding literature [11, 12, 14, 15, 17, 18] and [37], it follows that in the model of the larynx source two main blocks should be distinguished – the mechanical and aero-dynamical systems as shown in Fig. 12 [12].

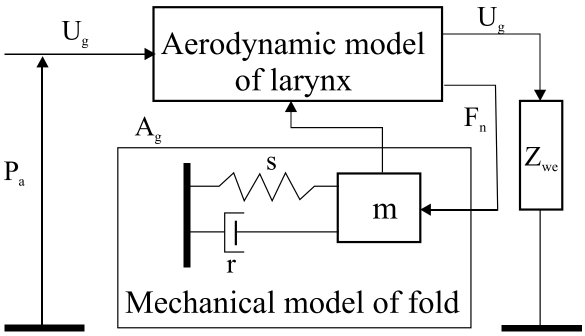

Fig. 12. General functional model of larynx source.

One set of reflects arise from the force acting on the walls of the voice folds (F_m) in the aerodynamical set, and the other one describes a modification of the glottis surface intersection A_g by the mechanical part of the glottis acting on the air stream flowing through it.

The model of larynx source shown in Fig. 12 illustrates in a general way that we have to take every time into consideration effects connected with the "mechanical part" and the "aerodynamic part" when modeling pathology. The model presented can be a basis of models which are going to simulate some larynx pathologies. There are plenty larynx simulation models. For the purpose of simulation, a two-mass larynx source model was applied [12, 16]. In this model, there is the possibility to simulate the basic physiological and pathological features of a larynx with a desired accuracy.

7. Research results

The research was limited to performing a comparison of a real pathological speech signal with the signal created by the model. A larynx defect caused by illness changes (polyp, Reinke's swallowing, singer's tumor) and surgical operation was considered as a voice channel pathology. In the concept of a **signal understanding** presented, the generation model represents the knowledge of arising of a pathological speech signal. In the outcome of the model, there is a signal in the form of a spectrum. The real pathological speech signal (coming from a particular patient), after processing it into the features vector, is also compared with the model output signal also transformed into the vector features form. On the basis of this comparison, the parameters of the model are changed so that the difference between the vector of the real signal features of a pathological speech and the signal generated by the model is minimized. In Fig. 13 an example of the /a/ vowel spectra is presented: the real signal (blue color) and the generated one (red color) for the correct speech.

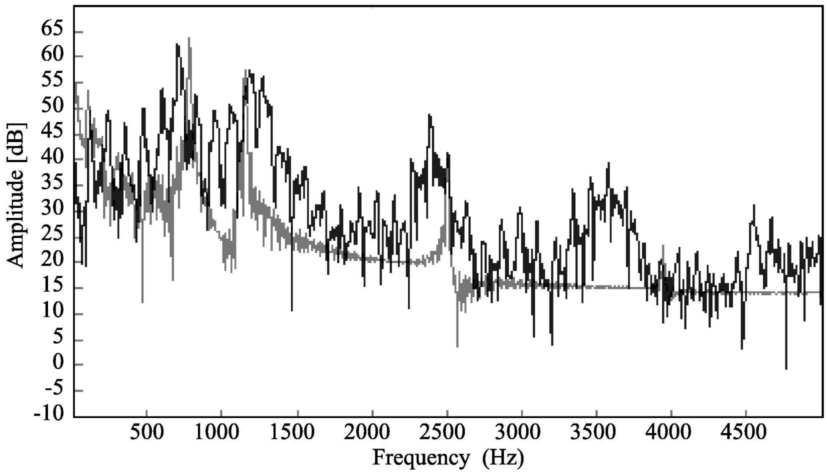

Fig. 13. Initial signal spectrum of simulation model (red color) and real speech signal (blue color) – the pattern signal.

In this way a pattern generation model of a speech signal was acquired. In Figs. 14 and 15, there are presented spectra of a pathological speech signal (blue color) and those acquired from the model (red color) for a patient suffering from a left voice fold polyp, before and after the surgical operation.

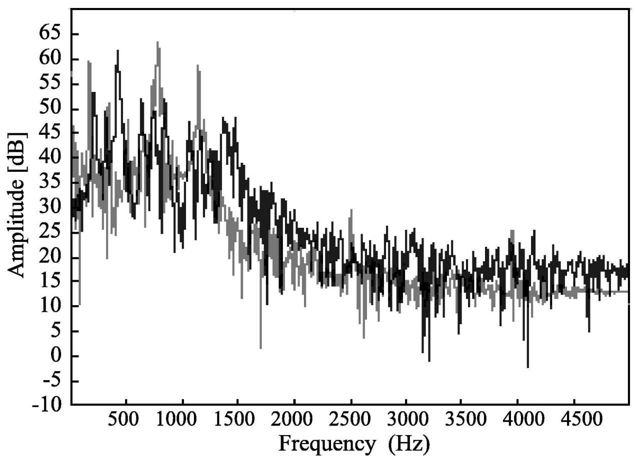

Fig. 14. Initial signal spectrum of the simulation model (red color) and the real speech signal (blue color) – polyp before a surgical operation.

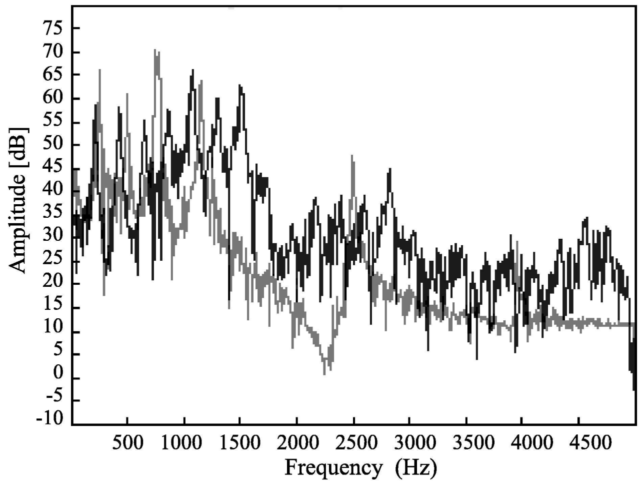

Fig. 15. Initial signal spectrum of the simulation model (red color) and the real speech signal (blue color) – polyp after a surgical operation.

In Figs. 16 and 17, the results acquired for the patient with Reinke's swallowing and in Figs. 18 and 19 those for the patient with singer's tumor were shown.

The introduced concept of a signal understanding consists in the incorporation of quantitative indices describing the issues of causes of signal changes (for example various voice channel pathologies).

The speech signals registered by a patient and the signal (in the spectrum form) generated by the signal generation model are transformed into the form of feature vectors and then compared regarding similarities (by the usage of metrics). The evaluation

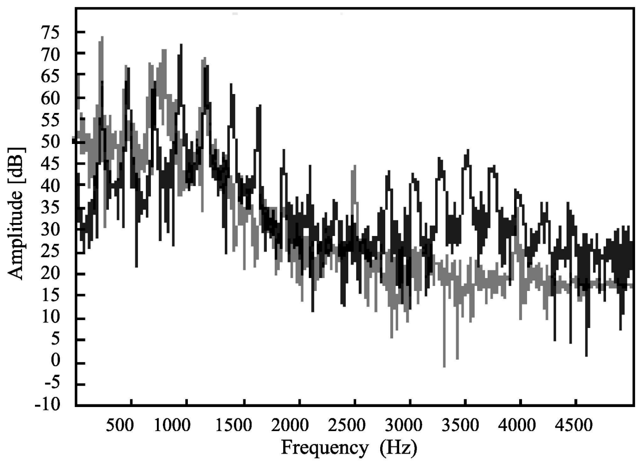

Fig. 16. Initial signal spectrum of the simulation model (red color) and the real speech signal (blue color) – Reinke's swallowing, before a surgical operation.

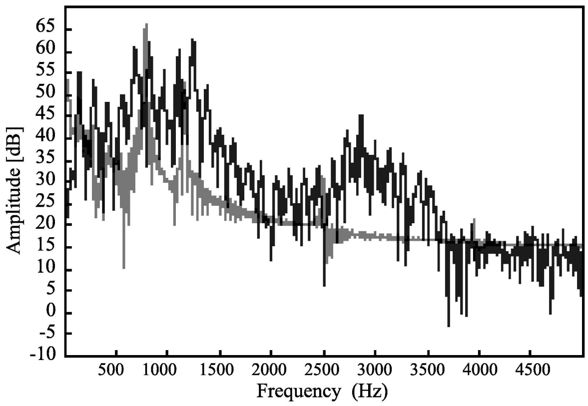

Fig. 17. Initial signal spectrum of the simulation model (red color) and the real speech signal (blue color) – Reinke's swallowing, after a surgical operation.

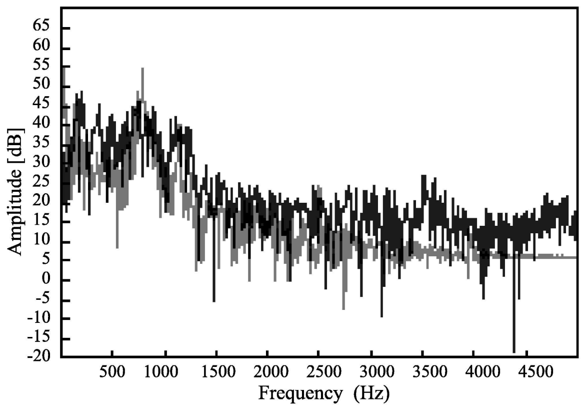

Fig. 18. Initial signal spectrum of the simulation model (red color) and the real speech signal (blue color) – singer's tumor, before a surgical operation.

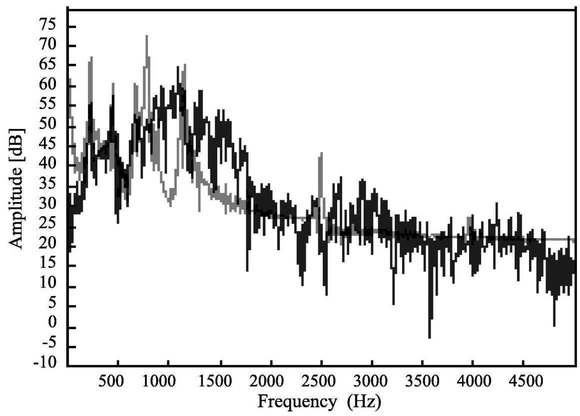

Fig. 19. Initial signal spectrum of the simulation model (red color) and the real speech signal (blue color) – Singer's tumor, after a surgical operation.

result is used to such a change of the appropriate parameters of the model in order to acquire the highest similarity of both the signals.

The size of the selected parameters of the model changes is the measure of the signal deformation, and the information on determining which ones of the model parameters are influenced by such a signal change in order to acquire the highest similarity that determines the level of deformation causes of “understanding”.

8. Summary and conclusions

The concept described comprises several elements which are difficult to realize. In case of a traditional way of solving diagnostic problems, it is often quite possible to acquire the answer more easily. The standard methods of speech signal analysis and classification, frequently used in recognition and analysis of normal speech, often fail to recognize and analyze the acoustic signal of a pathological speech [22]. In this type of methods one can distinguish the spectrum analysis (alternatively performed with the usage of the recently fashionable wavelet transformation technique), discriminatory analysis, linear prediction coefficients or the cepstral ones. These parameters are unable to describe the pathological speech in a satisfactory way because of its diverse phonetic and acoustic structures in relation to the correct speech signal, and moreover because of the reason that in this case the aim of recognition is completely different [23].

To sum up it can be stated that in the pathological speech automatic diagnosis area, it is necessary to create special methods of the automatic understanding of the nature of the processes that lead to a speech deformation and which would replace the presently applied methods of a typical analysis and recognition of sound signals and being adjusted to the particular problem specificity. It is generally well known that in the sound signals (pictures) analysis and recognition tasks, the methods of unification and standardization of algorithms encounter considerable difficulties. The main source of them is the fact that almost every task concerning a signal analysis is aimed at the obtaining of its other features and parameters, strongly connected with the specificity of the solved task and aiming at acquired answers to other questions. In connection with this, the method proposed has to be modified considerably when applying it to particular different tasks. The following methods have to be adapted: both the methods of initial acoustic signal transformation (which were omitted in this work – they were a subject of the previous publications), which should be directed towards the specificity of each identification task considered, as well as internal modelling techniques of various speech pathology generation processes. Also evolving techniques (recognition) of the optimum model have to be specific, as it already has been mentioned, the pathological speech analysis tasks are characterized by the fact that in this case it is difficult to talk about any form of a pattern signal, to which one could refer or link. In the future works, models of neuron acoustic signal generation of a pathological speech will be worked out.

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