Computer Simulation Modeling of Voice Signals in the Matlab Environment for the Task of Computerized Diagnostic Systems Testing

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Abstract

The paper shows the relevance of the task of the vocal apparatus organs diagnosing through proper processing of voice signals in computerized diagnostic systems. At the same time, the diagnostic decision and subsequent medical measures will depend on the quality and reliability of the results of such processing. In addition, it is important to ensure the possibility of testing both processing methods and software of such diagnostic systems in terms of sensitivity to manifestations of signs of individual pathological conditions of the vocal apparatus in the structure of voice signals. For this, a simulation mathematical model of the class of vocalized fricative sounds, as the most sensitive to changes in the functional state of the vocal apparatus organs, in the form of a mixture of sinusoids with exponential decay at characteristic time levels, was developed. Using Matlab software, a method of computer simulation modeling of such signals has been developed, which allows obtaining signals with predetermined parameters for the state of medical norm or pathology and, accordingly, testing the methods of processing such signals and the software of computer diagnostic systems.

Keywords 1

Voice signal, simulation model, voice apparatus, medical diagnostics.

1. Introduction

The number of people with disorders of the human vocal apparatus is increasing every year. Timely diagnosis makes it possible to detect changes in the functional state of the vocal apparatus organs through proper processing of voice signals and to carry out preventive measures or choose a course of treatment. For objective diagnosis in medicine indirect methods are used, created on the basis of the system-signal concept, in which the voice signal is interpreted as a physical process that spreads from the investigated object and is a means of transferring information about this object. The effectiveness of the functioning of the diagnostic system is determined to a decisive extent by the methods of voice signals processing, which are the basis of the development of such a system software, and must have the means of extracting informative characteristics - signs of changes in the voice apparatus operation.

Works [1, 2, 3] show that the most informative in terms of medical diagnosis is the selection and processing of a separate class of voice signals - vocalized fricative sounds (VFS). The methods of such signals processing in automated diagnostic systems are determined by their mathematical model. Algorithms and software of such diagnostic systems are built on the basis of this methods. However, in order to testing the methods of processing, to evaluate the reliability of the results of processing VFS by these methods and, accordingly, the algorithms and software of diagnostic systems, it is necessary

CITI'2023: 1st International Workshop on Computer Information Technologies in Industry 4.0, June 14–16, 2023, Ternopil, Ukraine
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to develop a method of computer simulation modeling of the signal, which would take into account in its structure the main parameters of the medical norm and the pathology of the vocal organs apparatus state and would make it possible to provide parametric identification of the method of such signals processing in computer diagnostic systems with reliable data reproduction [4, 5].

2. Simulation of voice signals

The first stage of simulation model development is the transition from a real physical object - VFS, to its mathematical representation [6, 7], which should take into account the characteristics of such sounds that are essential for the tasks of diagnostic systems testing. First, we will consider the mechanism of VFS creating in order to highlight informatively important characteristics for the tasks of medical diagnosis, which should be embodied in the simulation model of such signals.

When creating voice signals (VFS), in the air flow (Figure 1) the signal source forms a sound signal with a characteristic repeatability - the main tone (Figure 1), which is generated by the vocal folds ($p(t)$), (Figure 1, Figure 2). The articulation apparatus forms the phonetic structure of the signal $x(t)$ (Figure 1, Figure 2).

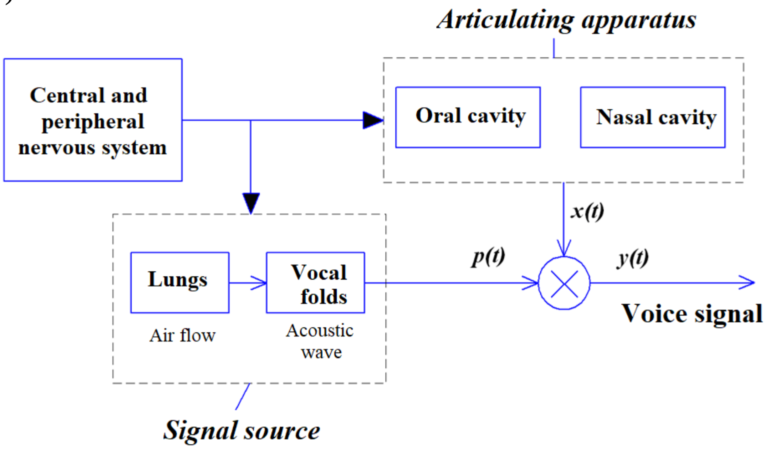


Figure 1: The process of VFS creating

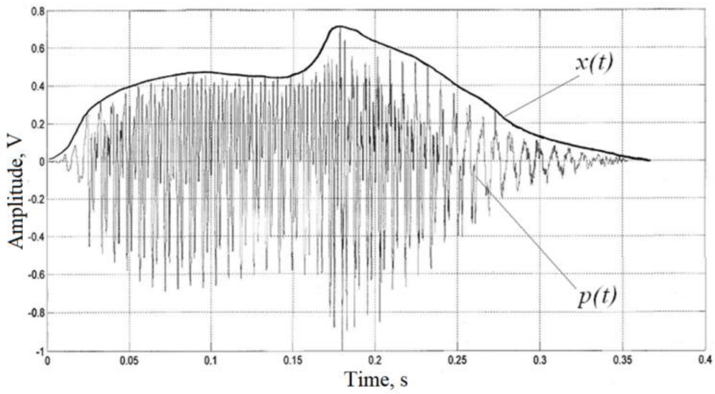


Figure 2: VFS as a result of the voice creating process

Thus, the voice signal *y(t)* can be represented as a pulse of an amplitude-modulated acoustic signal in the form of expression (1) [6]:

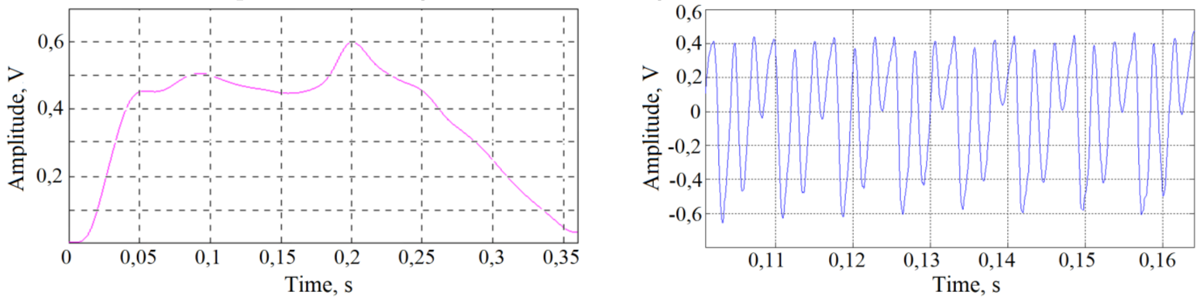
$$y(t) = p(t) \cdot x(t), \quad t \in [0, \tau_{pulse}] \tag{1}$$

where *p(t)* is a carrier component of the signal, which characterizes the operation of the signal source; *x(t)* is the envelope component of the signal in the time domain, which characterizes the behavior of the articulatory apparatus organs in time, τ_{pulse} – the pulse duration (signal duration).

Pathological changes in the organs of the signal source will be manifested in a change in the time and energy characteristics of the carrier component of signal [8, 9, 10]. Similarly, a disfunction of the articulation apparatus will be manifested in a change in the corresponding characteristics of the envelope component of signal.

Analysis of the carrier component and envelope component of the VFS in the time, frequency, frequency-time domains will make it possible to evaluate the work of the signal source and the articulation apparatus as a whole and its organs in particular.

To determine the time and amplitude characteristics of the carrier component and envelope component of the VFS, their selection was carried out using the method described in the paper [6] and the tools of the Matlab application program package. Graphs of the envelope component and sample from the carrier component of the signal are shown in Figure 3.



a) b)

Figure 3: View of the envelope component (a) and sample from the carrier component (b) of the signal – VFS

Since the main information parameters of the VFS are the energy and time characteristics of its envelope component and carrier component, as can be seen from Figure 3, then the mathematical model should take these parameters into account. At certain intervals, the carrier component of VFS behaves as a complex mixture of sinusoids (Figure 3, b). Characteristic points and amplitudes of the carrier component of VFS within one period are shown in Figure 4.

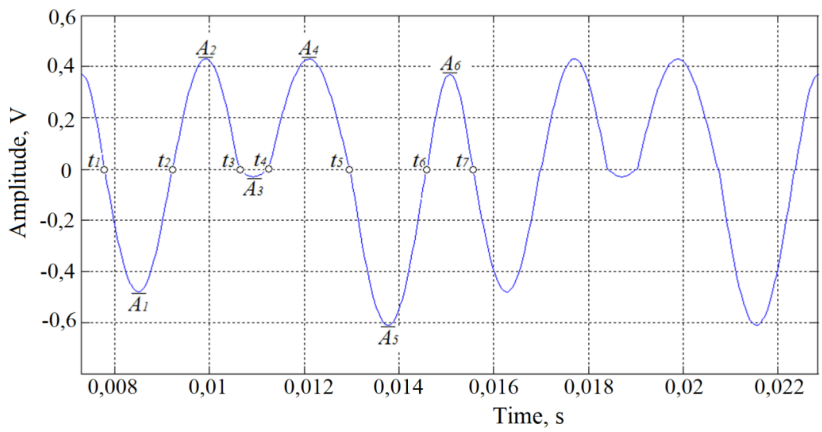


Figure 4: Characteristic points and amplitudes of the carrier component of VFS within one period

We build a model of the carrier component of VFS signal in the form of a complex mixture of sinusoids [11], which takes into account the characteristic points and amplitudes of the signal within the period:

$$p(t)=\begin{cases} A_1\sin(2\pi f_1 t)\cdot e^{-t\cdot K_1}\cdot S_1 & t\in[t_1+nT, t_2+nT] \\ A_2\sin(2\pi f_2 t)\cdot \mathrm{e}^{t\cdot K_2}\cdot S_2 & t\in[t_2+nT, t_3+nT] \\ \dots\dots\dots\dots & \dots\dots\dots\dots \\ A_6\sin 2\pi f_6 t\cdot e^{-t\cdot K_6}\cdot S_6 & t\in[t_6+nT, t_7+nT] \end{cases}, \quad n=0,1,2,\dots\infty \tag{2}$$

where: $A_1, A_2,\dots, A_6$ are the amplitudes of waves; $f_1, f_2,\dots, f_6$ are the frequencies of oscillations of sinusoids (in this case for a half period); $K_1, K_2,\dots, K_6$ are the slope coefficients; $S_1, S_2,\dots, S_6$ are the scale factors; T is the main period of the signal, which is the inverse of the main tone frequency of the VFS.

Similar methods of mathematical description of biosignals were considered in works [12, 13, 14].

Let's reduce the system of equations (2) to one expression:

$$p_j(t) = A_j \sin(2\pi f_j t) \cdot e^{-t \cdot K_j} \cdot S_j, \quad t \in [t_{1j} + nT, t_{2j} + nT], \; n = 0,1,2,...\infty \tag{3}$$

where j is the wave number at certain intervals $t \in [t_{1j} + nT, t_{2j} + nT]$.

In a similar way, we can write down the expression for the envelope component of VFS:

$$x_i(t) = B_i \sin(2\pi f_{oi} t) \cdot e^{-t \cdot K_{oi}} \cdot S_{oi} + N_i, \qquad t \in [t_{1i}, t_{2i}] \tag{4}$$

where i is the wave number at certain intervals $t \in [t_{1i}, t_{2i}]$, B_i is the amplitude of the i-th wave, f_{oi} is the frequency of oscillations of the i-th wave of the envelope component of VFS, K_{oi} and S_{oi} are the slope factor and scale factor of the i-th wave, N_i is the value of the constant component of the i-th wave of the signal.

The next stage is the actual computer simulation modeling and evaluation of the obtained results.

3. Results of computer simulation using Matlab software

Using previously obtained time and amplitude parameters of the carrier component of the voice signal in the normal state, a computer simulation of the carrier component of the voice signal was carried out in the MATLAB environment. In Figure 5 shows the sections of the carrier component of real and simulated signals. It can be seen the high degree of similarity of such signals. Incomplete compliance can be explained as follows.

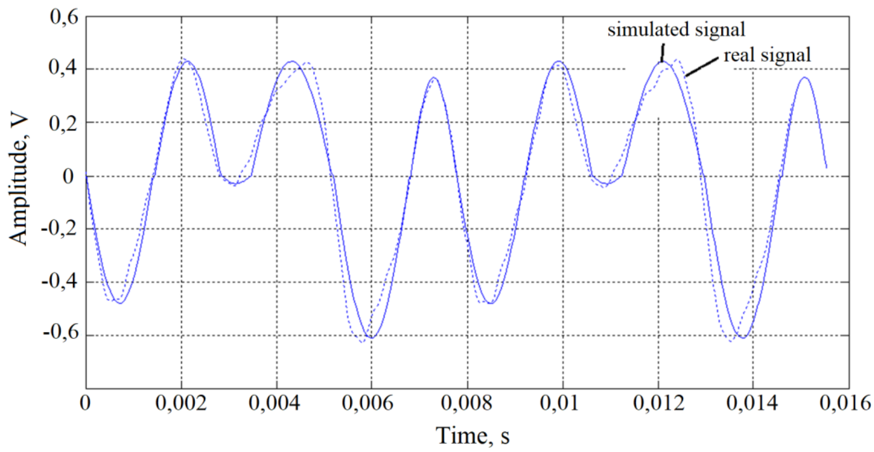


Figure 5: Comparison of samples from the carrier components of real and simulated VFS signals lasting 2 periods

Works [2, 3] show the presence of a random component in VFS signals, which depends on external and internal factors and forms of pronunciation disorders. In expressions (3) and (4), the amplitudes of the waves and their time durations are constant values, so we introduce a random component into these expressions:

$$p_j(l\Delta t) = (\psi_{A_j} + A_j) \cdot \sin\left(2\pi\left(l\Delta t + \psi_{T_j}\right) \cdot f_j\right) \cdot e^{-l\Delta t \cdot K_j} \cdot S_j, \; l \in \left[t_{1j} + nT, t_{2j} + nT\right] \tag{5}$$

$$x_i(u\Delta t) = (\psi_{B_j} + B_i) \cdot \sin\left(2\pi\left(u\Delta t + \psi_{T_j}\right) \cdot f_{oi}\right) \cdot e^{-u\Delta t \cdot K_{oi}} \cdot S_{oi} + N_i, \; u \in [t_{1i}, t_{2i}], \tag{6}$$

where: Δt is the VFS discretization step; j, i are the number of the value of the carrier component and the envelope component of the VFS, respectively; ψ_A is the random value of the wave amplitude of carrier component of the signal, distributed according to the normal law with mathematical expectation $M\{A\} = 0$ and dispersion $D\{A\}$, which is an indicator of deviation; ψ_B is the random value of the wave amplitude of the envelope component of the signal, distributed according to the normal law with mathematical expectation $M\{B\} = 0$ and dispersion $D\{B\}$, which is an indicator of deviation; ψ_T is the random value of the time duration of the wave is distributed according to the normal law with mathematical expectation $M\{N_T\Delta t\}=0$ and dispersion $D\{N_T\Delta t\}$, where N is the number of points that belong within one period of T of VFS, $N=\dfrac{T}{\Delta t}$.

Let's combine expressions (5) and (6) into one, which will be the expression of the simulation model of the VFS signal:

$$y_{ji}(u\Delta t)=p_j(l\Delta t)\cdot x_i(u\Delta t) \tag{7}$$

Using expressions (5)-(7), the results of computer simulation of VFS with different amplitudes and durations within the normal limits were obtained, which were implemented as a program in the Matlab R2015b environment and shown in Figure 6.

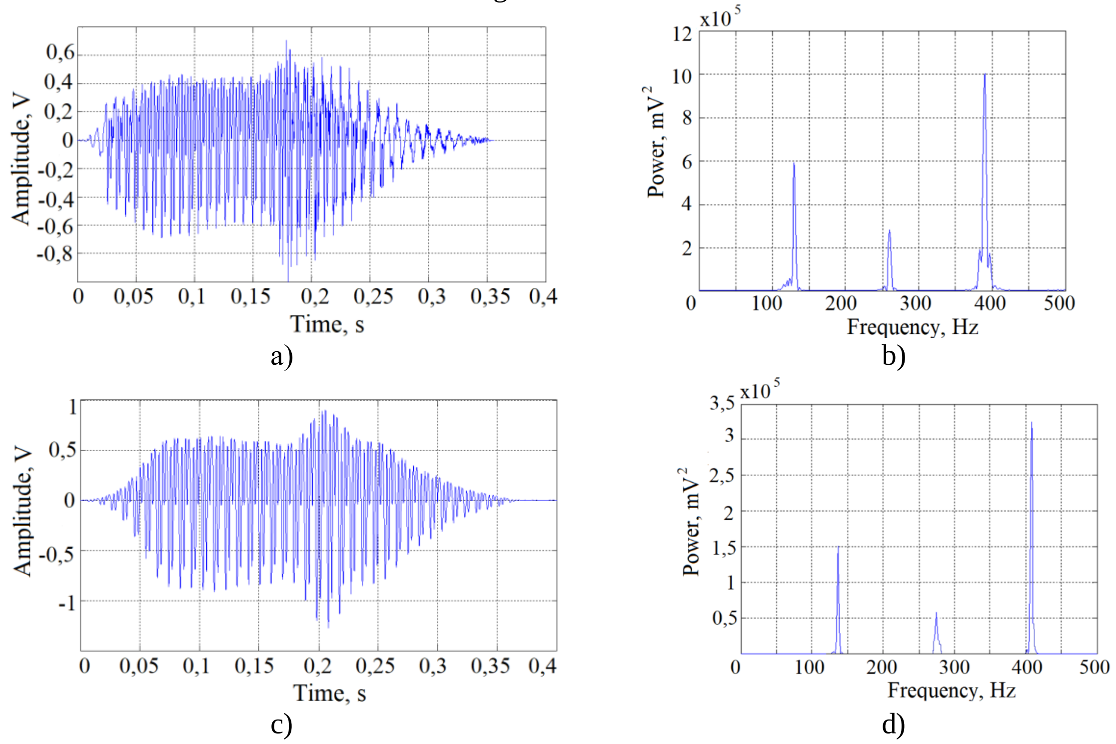


Figure 6: Implementations and estimations of the power spectral density of the real (a, b) and simulated signal – VFS (c, d)

From Figure 6 it can be seen that the time realizations of the real and simulated signals (VFS) are similar, and the ratio between the maxima in the power spectral density distributions of these signals, called formants, is preserved, which indicates the suitability of the developed simulation model for testing computer diagnostic systems, which are based on the methods of formant and probabilistic analysis of voice signals, since the values of probabilistic characteristics of the simulated signal are known in advance and embedded in the model.

In the following scientific works, it is planned to develop a software complex for modeling vocalized fricative sounds by analogy with [15, 16] and to propose new diagnostic features, as was done in the works [17, 18].

4. Conclusion

The developed simulation model of vocalized fricative sounds in the form of a complex mixture of sinusoids makes it possible to simulate signals for normal and pathological states based on known medical parameters. Based on the developed simulation model, a package of computer programs was created for statistical processing and simulation modeling of vocalized fricative sounds as a component of specialized software of medical automated diagnostic systems.

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