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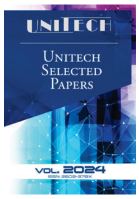

THE ASSESSMENT OF INTELLIGIBILITY OF SPEECH IN THE AMBIENTAL CONDITIONS OF THE OFFICE

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Abstract

In this paper the assessment of speech intelligibility in the presence of different types of noise in a situation that happen in real life in ambient of office. In order to evaluate speech intelligibility in the presence of different kinds of noise, an experiment was conducted, using the binaural method. Matrix sentences obtained from words from the Serbian Matrix Sentence Test Base (SMST) were used as an input signal. The interference signals that were used: diffuse noise, and a combination of different types of noise that occur in the office environment (sound of a pen, keyboard, etc.) as well as early reflections. The parameters used for testing: SNR = (0, - 2, -5) dB; b) speech signal angle $\phi s = 0°$; c) angle of reflection $\phi n = 0°$; e) angle of diffuse noise $\phi DN = 0 : 5 : 360°$, e) amplitude of reflection $Ar = 1$; f) delay time between direct and reflected signal $\Delta t = (0, 10, 25, 50)$ ms. The result of the test that is obtained is the STOI coefficient, for the left and for the right ear. After analyzing the results and comparing them with the results of similar tests and the IEC 60268-16:11 standard, a conclusion was brought about speech intelligibility.

Keywords: Intelligibility, SMST base, STOI, noise, binaural.

INTRODUCTION

In assessment of speech intelligibility in the presence of various noise: babble [1], industrial [2], rain [3] etc., different testing methods were used with appropriate types of speech materials for testing words [4] or sentences [5]. Many authors dealt with this topic using different methods approach. For testing speech intelligibility in the Serbian language authors was formed Serbian Matrix Sentence Test (SMST) base [6]. Test sentences are generated by random law of words from the SMST database, with respect specific form: name, verb, number, adjective, noun. In this paper the assessment of speech intelligibility in the presence of different types of noise in a situation that happen in real life in ambient of office. In order to assessment speech intelligibility in the presence of different kinds of noise, an experiment, using the binaural method, was performed. As a results of testing the dSTOI coefficient [7] was obtained for left and right ear. Comparing results of testing with of similar tests and the IEC 60268-16:11 standard [8], a conclusion was brought about speech intelligibility.

The organization of work is as follows. Section II describes experiment, experimental results and analysis. Section III is conclusion.

EXPERIMENTAL RESULTS AND ANALYSIS

A. THE EXPERIMENT

In aim to estimate the intelligibility of speech in the presence of noise in the office

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environment, the experiment shown in Fig. 1 was provided.

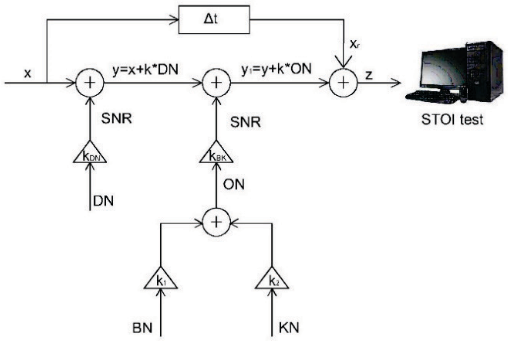
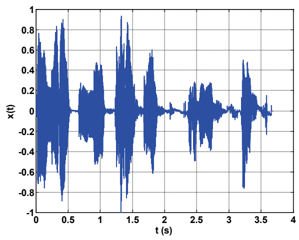


Fig. 1. *Block diagram of the experiment*

A test signal *z* was obtained by combining the reflected speech signal x_r with diffuse noise *DN*, and office ambient noise *ON*, with the desired signal-to-noise ratio (SNR) y_1. Matrix sentences composed of words from the SMST base were used as an input signal *x*. Diffuse noise is superimposed on signal *x*, as well as noise obtained by a combination of babble noise *BN* and noise caused by fast typing on the keyboard *KN* (to obtain the noise of an office environment, e.g. Office noise *ON*). The signal *y* is created by superimposing the speech signal x, and the diffuse noise *DN*, with the desired SNR, which is obtained by adjusting the coefficient k_{DN}. The signal y_1 is created by superimposing the signal y and Office noise *ON*, with the desired SNR, which is obtained by adjusting the k_{BK} coefficient. Office noise *ON* is generated by superimposing Babble noise *BN* and Keyboard noise *KN*, adjusting coefficients k_1= (0, 0.5, 1) and k_2, where $k_2 = 1 - k_1$. Babble noise and keyboard noise caused by fast typing on the keyboard are available on [9].

When coefficient have value: a) $k_1 = 0$, *BN* dominates, b) $k_1 = 0.5$ *BN* and *KN* signals have equal strength, and c) $k_1 = 1$, *KN* dominates. STOI coefficients were determined from the generated Test matrix sentences in Serbian: a) TS_1: '*Tamara ima šesnaest crvenih stolica*' (in English: '*Tamara has sixteen red chairs*'), b) TS_2: '*Marina pravi pet novih stolica*' (in English: '*Marina makes five new chairs*'), and c) TS_3: '*Tomislav čisti petnaest različitih stolica*' (in English: *'Tomislav clears fifteen different chairs*'). The time and spectral characteristics of the Test signals (TS_1, TS_2 and TS_3) are shown in Fig. 2 (TS_1), Fig. 3 (TS_2) and Fig. 4 (TS_3), for $SNR_{DN} = SNR_{ON} = -2$dB: speech signal $\boldsymbol{x}$, sentences obtained from the SMST base in Serbian language (a, b), reflected speech signal $\boldsymbol{x_r}$ (c, d) and, interference signal $\boldsymbol{y_1}$, ON, (e, f), and test signal $\boldsymbol{z}$ (g, h). The parameters used in the realization of the binaural experiment, and on the basis of which the intelligibility testing is performed using the STOI test are: SNR = (0, - 2, -5) dB; b) excitation angle of speech signal $\phi s = 0°$, c) angle of reflection $\phi n = 0°$; e) angle of diffuse noise $\phi_{DN} = 0 : 5 : 360°$, e) amplitude of reflection $Ar = 1$, f) delay time between direct and reflected signal Δt = (0, 10, 25, 50) ms. Testing was done for cases, when: a) $SNR_{DN} = SNR_{ON}$ and b) $SNR_{DN} \neq SNR_{ON}$. The result of the of the experiment, are the coefficients STOI, which were obtained using the STOI algorithm, for the left ($dSTOI_L$) and for the right ($dSTOI_R$) ear.



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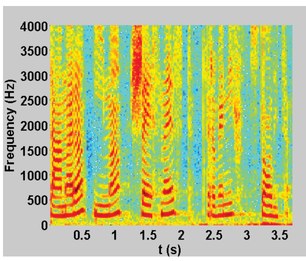

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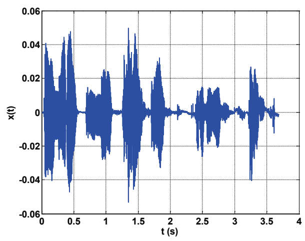

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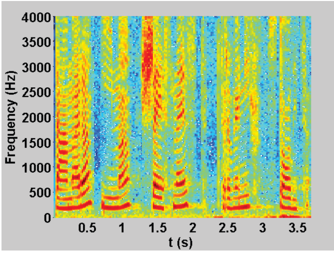

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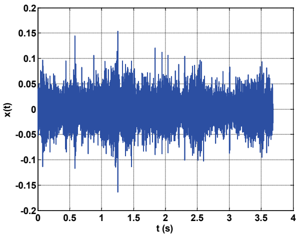

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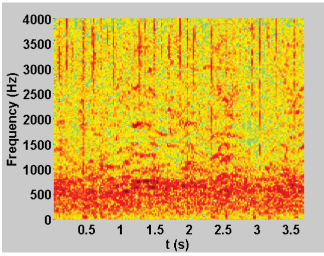

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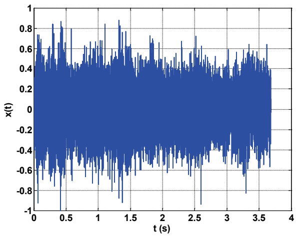

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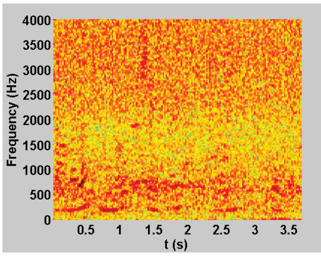

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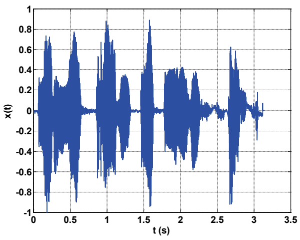
Fig. 2. *Time and spectral characteristic TS_1, for $k_1 = 0.5$, $\Delta t = 25ms$: TS_1 (a, b). Time of delay TS_1 25 ms (c, d). Office noise (e, f). TS_1 with superimposed noises (g, h).*



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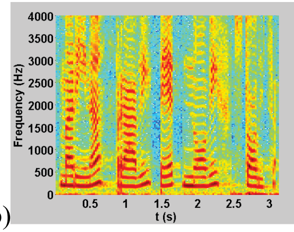

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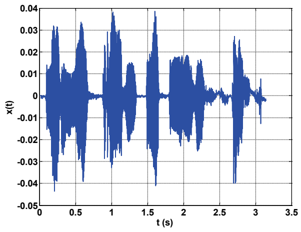

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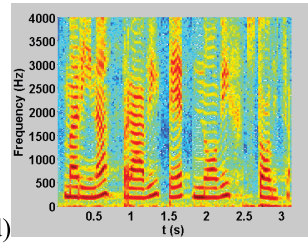

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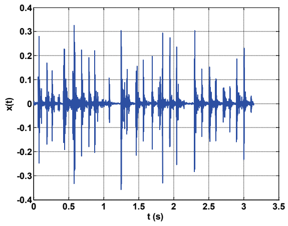

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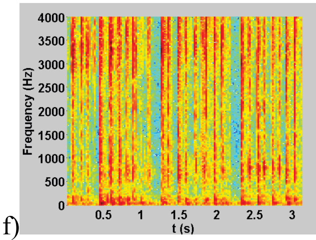

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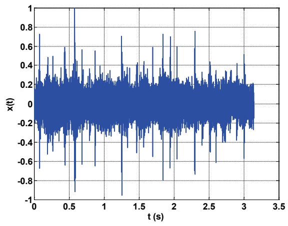

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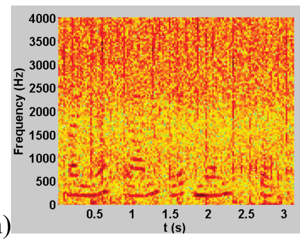

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Fig. 3. *Time and spectral characteristic TS_2, for $k1 = 0$, $\Delta t = 25ms$: TS_2 (a, b). Time of delay TS_2 25 ms (c, d). Office noise (e, f). TS_2 with superimposed noises (g, h).*

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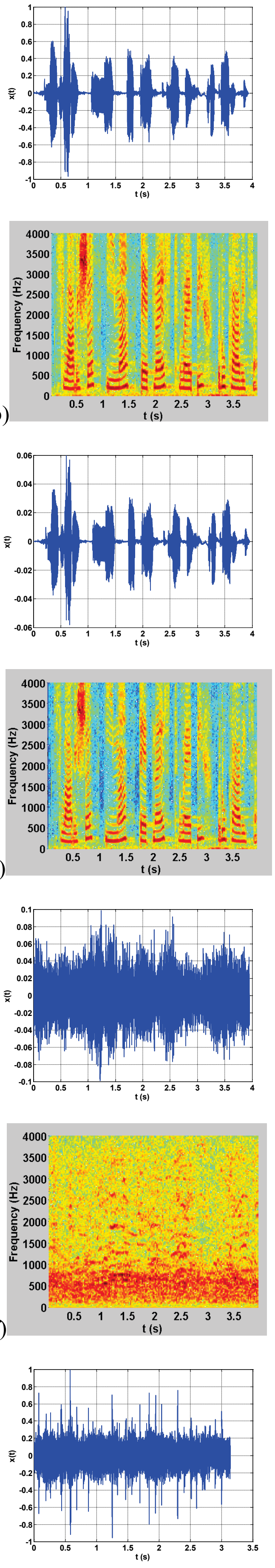

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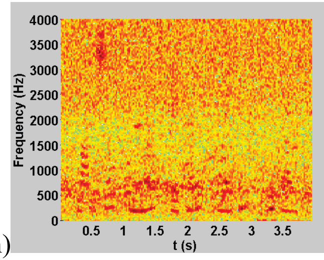

Fig. 4. *Time and spectral characteristic TS_3 for $k_1 = 1$, Δt=25ms: Test sentence TS_3 (a, b). Time of delay TS_3 25 ms (c, d). Office noise (e, f). TS_3 with superimposed noises (g, h).*

B. THE RESULTS

The test results (intelligibility coefficients dSTOI) are presented in tabular form, for $SNR_{DN} = SNR_{ON}$, and values of the coefficient k_1: a) $k_1 = 0$ (Tbl. 1), b) k1 = 0.5 (Tbl. 2), and c) $k_1 = 1$ (Tbl. 3). The intelligibility coefficients dSTOI, are presented in tabular form, for $SNR_{DN} \neq SNR_{ON}$, and values of the coefficient k_1: a) $k_1 = 0$ (Tbl. 4), b) $k_1 = 0.5$ (Tbl. 5), and c) $k_1 = 1$ (Tbl. 6).

TABLE I. INTELLIGIBILITY $k_1 = 0$, $SNR_{DN} = SNR_{ON}$

SNR (dB)	dSTOI	***Intelligibility*** Δt (ms) 0	10	25	50	μ
0	$dSTOI_L$	0.5687	0.5577	0.5401	0.6854	0.5880
	$dSTOI_R$	0.5734	0.5706	0.5538	0.6880	0.5964
-2	$dSTOI_L$	0.4486	0.5508	0.5931	0.6759	0.5671
	$dSTOI_R$	0.4599	0.5414	0.6011	0.6845	0.5717
-5	$dSTOI_L$	0.6133	0.5370	0.5408	0.5392	0.5576
	$dSTOI_R$	0.6268	0.5465	0.5362	0.5240	0.5584

TABLE II. INTELLIGIBILITY $k_1 = 0.5$, $SNR_{DN} = SNR_{ON}$

SNR (dB)	dSTOI	***Intelligibility*** Δt (ms) 0	10	25	50	μ
0	$dSTOI_L$	0.6995	0.5751	0.5704	0.5801	0.6063
	$dSTOI_R$	0.6971	0.5721	0.5773	0.5725	0.6048
-2	$dSTOI_L$	0.6365	0.5634	0.5188	0.5190	0.5594
	$dSTOI_R$	0.6294	0.5672	0.5037	0.5263	0.5567
-5	$dSTOI_L$	0.5809	0.4924	0.4810	0.4530	0.4999
	$dSTOI_R$	0.5825	0.4916	0.4748	0.4359	0.4962

TABLE III. INTELLIGIBILITY $k_1 = 1$, $SNR_{DN} = SNR_{ON}$

Intelligibility						
SNR (dB)	dSTOI	Δt (ms)				
		0	10	25	50	μ
0	$dSTOI_L$	0.7118	0.5138	0.5777	0.5430	0.5866
	$dSTOI_R$	0.7083	0.5190	0.6005	0.5433	0.5978
-2	$dSTOI_L$	0.6472	0.5744	0.6106	0.5177	0.5875
	$dSTOI_R$	0.6359	0.5708	0.6130	0.5279	0.5869
-5	$dSTOI_L$	0.5675	0.4658	0.5321	0.4638	0.5073
	$dSTOI_R$	0.5715	0.4708	0.5201	0.4776	0.5100

TABLE IV. INTELLIGIBILITY $k_1 = 0$, $SNR_{DN} \neq SNR_{ON}$

Intelligibility						
SNR (dB)	dSTOI	Δt (ms)				
		0	10	25	50	μ
-2	$dSTOI_L$	0.7093	0.5615	0.5845	0.5090	0.5911
	$dSTOI_R$	0.7220	0.5700	0.5875	0.5167	0.5990
-5	$dSTOI_L$	0.5900	0.5474	0.5600	0.4644	0.5404
	$dSTOI_R$	0.5920	0.5507	0.5695	0.4669	0.5448

TABLE V. INTELLIGIBILITY $k_1 = 0.5$, $SNR_{DN} \neq SNR_{ON}$

Intelligibility						
SNR (dB)	dSTOI	Δt (ms)				
		0	10	25	50	μ
-2	$dSTOI_L$	0.6365	0.5940	0.5354	0.4968	0.5657
	$dSTOI_R$	0.6340	0.5932	0.5416	0.4980	0.5667
-5	$dSTOI_L$	0.6252	0.5351	0.5059	0.4520	0.5295
	$dSTOI_R$	0.6218	0.5291	0.5055	0.4587	0.5288

TABLE VI. INTELLIGIBILITY $k_1 = 1$, $SNR_{DN} \neq SNR_{ON}$

Intelligibility						
SNR (dB)	dSTOI	Δt (ms)				
		0	10	25	50	μ
-2	$dSTOI_L$	0.6874	0.5105	0.5075	0.5714	0.5692
	$dSTOI_R$	0.6848	0.5163	0.5003	0.5719	0.5683
-5	$dSTOI_L$	0.6467	0.4658	0.5321	0.4638	0.5271
	$dSTOI_R$	0.6424	0.4708	0.5201	0.4776	0.5277

C. THE ANALYSIS

Analyzing the results the coefficients STOI, which were obtained using the STOI algorithm, for the left ($dSTOI_L$) and for the right ($dSTOI_R$) ear (Tbl. 1 – Tbl. 6), it was observed that the coefficients intelligibility $dSTOI_L$ and $dSTOI_R$ goes from: a) 0.4486 - 0.6880 for k_1=0, $SNR_{DN} = SNR_{ON}$ and 0.4644 - 0.7220 for $SNR_{DN} \neq SNR_{ON}$, b) 0.4530 - 0.6995 for $k_1 = 0.5$, $SNR_{DN} = SNR_{ON}$ and 0.4520 - 0.6365 for $SNR_{DN} \neq SNR_{ON}$, and c) 0.4638 - 0.7118 for $k_1 = 1$, $SNR_{DN} = SNR_{ON}$ and 0.4638 - 0.6874 for $SNR_{DN} \neq SNR_{ON}$. The best intelligibility were obtained for $SNR_{DN} = SNR_{ON}$ = -2dB dB is $dSTOI_R$ = 0.7220 and $dSTOI_L$ = 0.7093. It can also be observed that, in general, the intelligibility at SNR = -2dB is better than for the other cases (SNR = 0 and SNR = -5). Also, by increasing the time of delay to Δt = 25ms, or 50ms, an improvement in speech intelligibility is observed. By comparing the results obtained for the left and right ear, results are generally better for right ear, which proves theory of research Audiology researchers at Auburn University in Alabama [10].

Analysing of many study which tested influence of noise in office environments showed a negative effect on employees. Some of them have influence on health, other on productivity. As a primary source of noise annoyance for other employees show that the conversation between individuals and their colleagues (Babble noise) [11]. Besides on intelligibility of speech, the noise have a negative effect on employees ability to focus to performing their tasks [12], and also increased frustration and stress among employees [12]. A study performed by Oseland stated that 92% of employees reported that noise made their job performance less productive [13].

CONCLUSION

The paper presents the results of the experiment, which relate to intelligibility in conditions of diffuse noise *DN*, office noise *ON*, which consists of babble *BN* and keyboard noise *KN*, as well as reflection. Intelligibility is represented by the intelligibility coefficient, which was determined using the STOI algorithm, for the left ($dSTO_L$) and right ($dSTOI_R$) ear. By comparing the results coefficients intelligibility, obtained experimentally for different value of SNR, and analyzing the time and spectral characteristics of the signals, it is observed, that the babble noise

BN intensively affects the degradation of intelligibility. This stems from the fact that *BN*, which is a consequence of the speech of a large number of people, has an energy distribution in the spectrum that is equivalent to the energy distribution of a speech signal. In this way, time and spectral masking of the speech signal is intensively performed, so that *BN*, in relation to *DN*, reflections and *KN*, has a dominant degradation of intelligibility. By comparative analysis of the experimental coefficients of intelligibility (range 0.4486 to 0.7220) with classification coefficients of intelligibility defined by standard IEC 60268-16, it is concluded that speech intelligibility in the ambient conditions of Office, with the parameters tested (SNR = (0, - 2, -5) dB, signal $\phi s = 0$, $\phi n = 0°$, $\phi_{DN} = 0 : 5 : 360°$, $Ar = 1$, $\Delta t = (0, 10, 25, 50)$ ms, $k_1 = (0, 0.5, 1)$), is poor.

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