VINKO DVOŘÁK SLIDING TONES: DO THEY EXIST?

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UDC: 781.1

Original Scientific Paper
Izvorni znanstveni rad
Received: September 14, 2006
Primljeno: 14. rujna 2006.
Accepted: September 30, 2006
Prihvaćeno: 30. rujna 2006.

Abstract — Résumé

We are analysing variations (sliding tones) and combination tones in bird (thrush) song, following the early work of Vinko Dvořák. He was a research pioneer in determination of the critical bands of hearing, experimenting with the pitch of combination tones with frequency difference between the highest and lowest tones. Instantaneous frequency monitoring was realised after a spectrogram done with SFSWin, and the signal from the bird song record was then transformed with the Hilbert transform. An analytical signal comes from combining this transform with the original signal. There is no amplitude modulation. Analysis of the records of the bird song does not show any unexpected tone at normal loudness, contrary to early experiments where very high intensities were used, causing post experimental TTS and tinnitus.

Key Words: sliding tones; variation tones; combination tones; thrush; pipe; resonator; spectrogram; instantaneous amplitude; instantaneous phase; instantaneous frequency; Hilbert transform; critical band

1. *Introduction*

In 1874, Vincenc (Vinko) Dvořák described »a new kind of variation tones«.[1] He was living in Prague the first time he heard this tone in thrush bird song, the bird very likely being the thrush (*turdus philomelos*). He believed that the frequency of this tone was the difference between the highest and lowest frequency of the fast changed (slide) pitch. In his paper, Dvořák described an experiment with pipe sound source with changeable length generating a sweep tone. He was changing the pipe length between two defined length positions defining the upper and lower frequency approximately three times up and down in one second, producing a sweep signal. The sound source generated a single tone of high loudness, and, apart from this tone, Dvořák claimed that he was able to hear the constant low frequency tone with frequency equal to the difference of the sweep range. After investigating species of birds in the Prague area, we find it highly probable that Dvořák heard *turdus philomelos*. Dvořák also mentioned in his paper that what he heard was generated in the ear, because the level of this tone was not increased with an external resonator, which is a very strong argument. Branko Hanžek wrote after Dvořák about the philosophical and historical insight of sliding tones.[2]

When the pitch of the tone varied, then, besides the original tone, the sound of a new by-tone could be heard. The thrush would slide from one tone to the other so that one tone would merge into another smoothly, and not in leaps. Dvořák heard that tone again while experimenting with a pipe, changing the length of the column of air in the pipe with varying speed. By precise measuring he determined the explicit dependence of the pitch of the tones on the length of the column of air in the pipe, comparing the tones produced by the pipe with the tones produced by jerking cords of different lengths on the monochord. In his article he also represented that dependence graphically. After processing the results of measuring numerically, he concluded that the sliding tone (a new kind of tone given this name because of its shortness) had the same pitch as the combination tone, but that there were some differences. One of the components in their similarity is that they are both issued in the ear and cannot be magnified like other tones. The difference between them is that, as in the case described in the mentioned article, the combination tone causes the sliding tone to be inaudible, and the pitch of the sliding tone, within certain limits, is independent of changing the height of the column of air in the two pipes, as opposed to the created combination tone, that is

[1] Vincenc (Vinko) DVOŘÁK, »Über eine neue Art von Variationstönen«, *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften*, Band LXX,1874, 1-9 (offprint), Vienna.

[2] Cf. Branko HANŽEK, The Genealogy of Science and Acoustics — A Supplement to the Description of the Role of Vinko Dvořák, *International Review of the Aesthetics and Sociology of Music*, Vol. 35, No. 2 (December 2004), 183-210.

issued only by increasing the length of the column of air in the pipe, and not by shortening. The most unusual characteristic of the sliding tone is that its pitch, within certain limits, is not dependent on the speed of lengthening or shortening of the column of air in the pipe. In case of very slow lengthening and shortening of the column of air in the pipe, the sliding tone becomes so low and weak that it is impossible to determine its pitch.

2. *Experiment Reproduction*

Records of bird songs can be found on J. C. Roché's CD *Tous les oiseaux d'Europe*,[3] and sweep-like sequences are present in *turdus philomelos* recording. The first step was to find and extract the sweep tone in the bird song. Analysis was performed by SFSWin*, originally developed for speech analysis. The spectral intensity at each point in time is indicated by the intensity (darkness) of the plot at a particular analysis frequency. First, five persons with normal hearing heard the extracted sequence in the repeated order with approximately 85 dB sound pressure levels (latter: SPL). Nobody identified any low frequency tones. The spectro-gram done with SFS is shown in Figures 1, 2, and 3.

Figure 1.

[3] J.C. ROCHÉ, *Tous les oiseaux d'Europe*, CD No. 3, SITTELLE, Châteaubois, 38350 La Mure, France.
* SFS Release 4.5/Windows, Version 1.4, http://www.phon.ucl.ac.uk/resource/sfs/

Figure 2.

Figure 3.

The upper spectrogram in Fig. 1 was generated by high time resolution, while a longer time window with better frequency resolution was chosen for the lower spectrogram. In Fig 2. only sweep sequence with high time resolution is shown. Note the frequency resolution, the second harmonic and a kind of side bands or intermodulations. For Fig. 3 frequency resolution was increased and the individual spectral harmonics corresponding to the pitch of the bird song waveform, during voiced regions, are resolved and are seen as almost horizontal limes in the spectrogram, but it was still not good enough to predict the expected Dvořák variation tone.

To overcome this problem Matlab and Simulink have been used for two purposes:

— The instantaneous frequency monitor was modelled on Simulink to gain better information about the frequency of the bird song;
— To generate the signal as used by Dvořák in his pipe experiment.

The instantaneous frequency monitor was realised as shown in Fig. 4. An analytic signal is a complex time signal whose imaginary part is the Hilbert transform of the real part. In the case of modulated signals, to model the signal in terms of a single phasor with varying amplitude and rotational speed (which can be termed instantaneous frequency). A generally modulated signal can thus be expressed as $g(t) = Re\{A(t)\, e^{j\Phi(t)}\}$ where the amplitude $A(t)$ and instantaneous phase angle $\Phi(t)$ are functions of time. The instantaneous frequency of the analytic signal $f(t)$ is calculated by taking the difference between the adjacent phase sample value of the instantaneous phase. Spectrum $A(f)$ of the analytic signal contains only positive frequency. The instantaneous phase is changed (unwrapped) to obtain a continuous function of $\Phi(t)$.

Figure 4.

The signal from the bird song record was transformed with Hilbert transform. An analytical signal comes from combining this transform with the original signal delayed by $^1/_2$ of the Hilbert transform length. The instant amplitude was analysed with a spectrum scope to see if any amplitude modulation in the interesting frequency range is present in the chirp signal, and there was none. The phase of the analytical signal was unwrapped and differentiated. The resulting frequency is shown on the scope (Fig. 5) (X-axis is time, Y is frequency).

Figure 5.

Note the frequency modulation, and the fact that the sweep is almost perfectly linear. The lowest frequency is about 2.5kHz, and the highest about 3.4kHz, the expected Dvořák combination tone is at 900Hz.

This tone was neither measured nor heard.

In the next step, the Dvořák pipe with changeable length, generating tone of variable frequency, was simply simulated as shown in Fig. 6.

Figure 6.

For the first experiment (one pipe with changeable length generating variable tone) Chirp Signal 1 was not used. The signal recorded in Chirp2.wav was generated as proposed by Dvořák, and reproduced to normal hearing subjects at 85dB SPL level. Nobody heard the low frequency component. In experiments with two pipes, Dvořák was holding tone f_2=3084 Hz constant, and changing the frequency of the lower tone from f_1=2056 Hz to unison ($f_1=f_2$), the musical interval was the fifth $f_2=3/2f_1$ (in Fig. 6 Chirp signal 1). The combination tone corresponded to the frequency f_{C1}=1028 Hz. In our experiments, it was determined that the pitch of the combination tones $f_{C1}=f_2-f_1$, $f_{C2}=2f_1-f_2$ and $f_{C3}=3f_1-2f_2$ was decreasing with frequency increase f_1 to unison. When listening to two pipes we have heard beats, and also very clearly we heard low combination tones and sliding tones with them (combination tones of variable frequency).

3. *Discussion and Conclusion*

In his experiment, Dvořák definitely used very high sound pressure levels. He described that he used a pipe and in the footnote he wrote: »The combination tone is very loud with this pipe, even louder than source tone…. At lower frequencies tones are localised in the head… If I repeat the experiment for a longer time, after experiments I can hear hissing and singing for a longer time, as I experienced when [we] had to fire a canon for a long time…«. The conclusion may be that Dvořák was exposed to high sound levels for a long time, and consequently suffered acoustic trauma and probably also tinnitus. In our experiments, the sound pressure was held at the acceptable level, and this could be the reason for our not experiencing Dvořák's sliding tones. In experiments with two pipes, when the frequency of the variable tone f_2 increases beyond the critical band, while f_1 is kept constant, Dvořák has heard beats, combination tones and sliding tones. He called these combination tones of variable speed sliding tones. Dvořák was a research pioneer in determination of critical bands of hearing, because in his experiments he was determining the pitch of combination tones with frequency difference between the highest and lowest pipe tones. In order to hear two constant tones, the frequency of the combination tone must fulfil the relation $f_C=\Delta f > \Delta f_{CB}$.

Acknowledgements

This article is a result of the research which has been partially supported by the Ministry of Science, Education and Sports of the Republic of Croatia, under Contracts 0037114 and 0036011.

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Sažetak

POSTOJE LI KLIZNI TONOVI VINKA DVOŘÁKA?

Vinko Dvořák je 1874. godine objavio rad »O novoj vrsti varijacijskih tonova«. Taj je ton prvi puta čuo kod glasnog pjevanja drozda u sobi. Drozd je s jednog tona prelazio na drugi klizeći. Taj je isti ton dobio malom sviralom kojoj se promjenom duljine mijenjala proizvedena visina tona (frekvencija). Kod slušanja je, uz tonove svirale, čuo još jedan duboki ton kojega je nazvao kliznim. Utvrdio je da je visina kliznog tona jednaka kombinacijskom tonu dobivenom iz razlike frekvencija najvišeg i najnižeg tona svirale. Budući da se ti tonovi nisu mogli pojačati u rezonatoru zaključio je da nastaju u uhu.

Poznato je da istovremenim slušanjem stalnog tona frekvencije f_1 i tona $f_2=f_1+\Delta f$ od unisona ($\Delta f=0$) do velike terce, kvinte ili oktave čujemo jedan ton kojem subjektivna visina tona (dalje: SVT) odgovara frekvenciji f_1. Ako polagano povećavamo frekvenciju f_2 čujemo jedan ton nešto veće SVT, koja odgovara frekvenciji $f=f_1+\Delta f/2$, kojem glasnoća titra frekvencijom treptaja $\Delta f=f_2-f_1$. Ako je $\Delta f>15$Hz treptaji nestaju i pojavljuje se subjektivni osjet tona, nazvan hrapavost (engl. *roughness*). Kada Δf prijeđe granicu razlikovanja frekvencija $\Delta f>\Delta f_D$ čujemo iznenada dva tona, dvije SVT (dva *pitch* signala), a osjet hrapavosti ostaje. Ako Δf prijeđe veću razliku frekvencija Δf_{CB} (kritični pojas) osjet hrapavosti nestaje i čuju se dva čista tona (engl. *smooth, pleasing*). Kada frekvencija varijabilnog tona f_2 naraste iznad kritičnog pojasa pojavljuje se dodatan osjet SVT-a (*lower pitch tone sensation*).

Istovremenim slušanjem stalnog tona f_1 i tona kojem se frekvencija f_2 mijenja polagano, od unisona do velike terce, kvinte, oktave i obratno, slušamo svaki ton s njegovom SVT i istovremeno jedan ili više tonova niskog SVT (*lower pitch tones*). SVT tih tonova raste i pada ovisno o smjeru promjene f_2. Ti tonovi, koji ne postoje u originalnom zvuku, su kombinacijski tonovi i njihova SVT odgovara frekvencijama $f_{C1}=f_2-f_1$, $f_{C2}=2f_1-f_2$ i $f_{C3}=3f_1-2f_2$. SVT kombinacijskih tonova se mijenja kontinuirano s promjenom frekvencije f_2.

V. Dvořák je u eksperimentima s dvije svirale držao ton f_2=3084 Hz konstantnim, a nižem tonu se mijenjala frekvencija od f_1=2056 Hz do unisona ($f_1=f_2$). Muzički razmak bio je kvinta $f_2=3/2f_1$. Za kombinacijski ton Dvořák je dobio vrijednost od f_{C1}=1028 Hz. Našim eksperimentima utvrđeno je da je SVT kombinacijskih tonova f_{C1}, f_{C2} i f_{C3} padala s porastom frekvencije f_1 do unisona. Pri slušanju dvije svirale Dvořák je čuo treptaje, a uz njih i s njima, istodobno i to posve jasno, duboke kombinacijske tonove i klizne tonove. Prema trenutnom stupnju znanstvene spoznaje Dvořákovi klizni tonovi su u stvari kombinacijski tonovi promjenjive visine.