Correlation between Three Facial Vibration Measurement Methods

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Abstract – **This paper deals with the facial surface vibration measurement performed by three different methods. Facial vibrations were measured during performing the resonance voice exercises with different shape of vocal tract or with different length of the resonance tube. Vibrations were measured on the upper lip by vibrometer and on the ala of nose by accelerometer. The amplitude of oscillation was also monitored by high speed camera in the direction x and y axes and also total amplitude. Correlations between all three methods showed a significant agreement in measurement. Two-way Analysis of Variance (ANOVA) with the type of vocal tract and pitch were applied. It revealed the significant differences of amplitudes of vibration dependent on the pitch and the vocal tract type.**

Keywords-vibration, accelerometer, vibrometer, high-speed camera, facial surface, resonant voice

I. INTRODUCTION

In recent years vibration measurement using optical full-field methods is being more spread in research and industry, e.g. vibration limits compliance control such as impact testing. These methods are based on taking images by high-speed camera and their analysis using digital image correlation [1].

In the voice measurement area facial vibrations have been associated with the production of resonant voice [2]. For parts of cheek vibration recording accelerometers or laser Doppler vibrometers are being used.

Study [3] described nasal bridge vibration measurement using the accelerometer. Results showed significantly higher magnitudes of facial bone vibrations caused by nasal stimuli as compared with non-nasal stimuli. Resonant voice as compared with strained and non-resonant voice produced the highest vibrations presented as RMS values of accelerometer signal measured in mV. Results of the other study [4] using accelerometers showed significant resonance increase in the nasal bridge area after resonant voice practice. It also found different values of vibration during different type of phonations. The highest values were recognized during phonations of nasal sounds and then for vocals “u”, “i” and “a”, so the vibrations decreased with the opened vowels.

Studies [5] and [6] dealt with facial vibration measurement using scanning laser Doppler vibrometer. Their results showed stronger vibrations presented as RMS values of vibration velocity in dB in the mouth opening area as compared with other face regions. During nasal consonant “n” production the vibration was stronger in the nasal area than during production of vocal “a”. Comparison of different vocals showed more vibrations around the nose during phonation of vowel “i”. During phonation in falsetto register vibrations around the cheek and forehead increased as compared with phonation in modal register.

Semi-occlusion or vocal tract narrowing in association with vocal tract lengthening by tube are widely used methods in voice education and therapy. They make possible better control of exhaled breath and they emphasize vibration feeling in the cheek area, they reduce oscillation threshold pressure and increase source-vocal tract interaction. Study [7] using models showed threefold increase of mouth pressure just behind the lips in the case of using resonance tube as compared with vocal “u”. Abovementioned results motivated us to use resonance tubes, vowel "u" and brumendo for vibration comparison measurement.

II. MOTIVATION AND GOALS

The main target of this study was to verify whether high-speed optical methods could relevantly identify facial surface vibrations. Therefore correlations between three different methods of facial surface vibration measurement during resonant voice production were looked for. Dependence of type and length of vocal tract and pitch was investigated. Vibrations were monitored by the piezoeletric accelerometer, the laser vibrometer and the high-speed camera.

III. METHODS

A. *Vibration Measurement Sensors and Placement*

The piezoeletric accelerometer type PCB Electronics 352C23 with sensitivity (± 20 %) 0.5 mV/(m/s2) was placed on the right side of the subject´s nasal bridge. To achieve a better grip on the skin surface a special wax was applied to the accelerometer and for more stability of the accelerometer on the nasal bridge, the sticking-plaster was also used. The accelerometer was connected with sensor signal conditioner PCB Piezoeletronics model

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480C02. For more comfortable monitoring the signal measured by accelerometer was amplified by measuring amplifier Brüel&Kjaer Type 2636.

The laser beam of vibrometer Polytec Fiber interferometer OFV 518 powered by electronic unit Polytec OFV 2802 I was focused to the reflective pad placed on the upper lip. The vibration measurement by vibrometer is based on the reflection of the beam back to the lens. Therefore the correct focalization was necessary for receiving a signal without artifacts. The sensitivity of vibrometer was 125 mm/(s.V). The distance between the vibrometer lens and the reflective pad placed on the subject´s upper lip was 110 cm.

The high-speed camera Vision Research Phantom speed sence v611 was placed on the tripod of the subject´s left side. The camera lens was directed to the left side of the subject´s face. The cheek, the lip and the nose were monitored. For more visibility subject used white greasepaint and his face was marked by black spots. The part of face scanned by the camera was highlighted by the Visera Xenon Light Source Olympus CLV-S45 (300 W). For mapping the highest face area, the angle of camera turning was 30 deg. Fig. 1 shows some camera image, where points on the nose and on the upper lip marked as "+" represent the positions of accelerometer and vibrometer, respectively on the opposite side of the cheek.

B. Participant

The subject participating on this pilot experiment was a man with the age of 37 years, researcher in acoustics focused on voice research and also with choir singing experiences. He was sitting on a chair and his head was fixed on the left, right and back side by special height and width adjustable device. The position of subject´s head was fixed, because if subject moved with his head the reflective pad placed on his upper lip would get out of the beam path and the beam would not reflect back to the lens. Subject´s eyes were protected by special blind glasses.

C. Procedures

Subject was asked to make few different resonant voice exercises with different shape of vocal tract (vowel "u" and closed brumendo) and with different length of resonance tube (29 cm and 60 cm respectively), with inner diameter 10 mm. In all utterances he was producing upward and downward scale with maximal possible intensity

D. Data Acquisition

Nasal ala vibration monitored by accelerometer, upper lip vibration monitored by vibrometer and high-speed video recording of the subject´s face in detail were measured simultaneously with acoustic signal recording.

The accelerometer and vibrometer were connected with external USB sound card M-Audio Fast Track Ultra. Signals monitored by both sensor types were recorded by PC software Audacity 1.3.13 communicating with the sound card by ASIO drivers. Sample frequency of recorded signals was 96 kHz. Accelerometer and vibrometer signals were recorded to separated tracks. Signal from each track was extracted to WAV file.

For more effective utilization of the high-speed camera subject was directed switching of high-speed sequencies with sample frequency 8000 fps by external synchronizing device at the time of the highest voice intensity of each tone. Otherwise the camera stayed in preview mode with sample frequency 10 fps. The image resolution was 512 x 1024 px. With current setup the camera could take 32434 for each exercise.

The acoustic signal was recorded by microphone placed in the distance of 15 cm from subject´s mouth. It was also connected with the sound card.

Data post-processing was performed in special software for voice signal processing RealVoiceLab v39 implemented in Matlab interface. Artifacts in voice range profile were detected and muted. Pitch (F0) and Sound Pressure Level (SPL) were extracted from acoustic signal. Then the amplitudes of vibration were calculated.

The signal voltage was detected in WAV files. In view of the fact that accelerometer measures acceleration whilst vibrometer measures velocity all data were recalculated to amplitude to make the comparison with each other and also with data monitored by high-speed camera possible.

To calculate the amplitude of accelerometer data double integral of acceleration had to be used while acceleration was defined as a quotient of voltage and accelerometer sensitivity

$$Aa(t) = \iint u(t)/\mathrm{SA}\ \mathrm{d}t, \tag{1}$$

where Aa means amplitude of accelerometer, u means voltage, t means time and SA means sensitivity.

To calculate the amplitude of vibrometer data integral of velocity had to be used while velocity was defined as a product of voltage and vibrometer sensitivity

$$Av(t) = \int u(t).\mathrm{SV}\ \mathrm{d}t, \tag{2}$$

where Av means amplitude of vibrometer, u means voltage, t means time and SV means vibrometer sensitivity.

Recording of high-speed camera was analyzed by software VIC-2D 2009 Digital Image Correlation, version 2009.1.0. Mean values of amplitudes in the direction x and y axes of each period and also total amplitude of each segment corresponding with measurement of high-speed sequences were calculated from relative amplitudes in the direction x and y axes monitored at positions corresponding with nose and lip movement. The cheek was monitored by high-speed camera from the opposite side than vibrations were monitored by accelerometer and vibrometer.

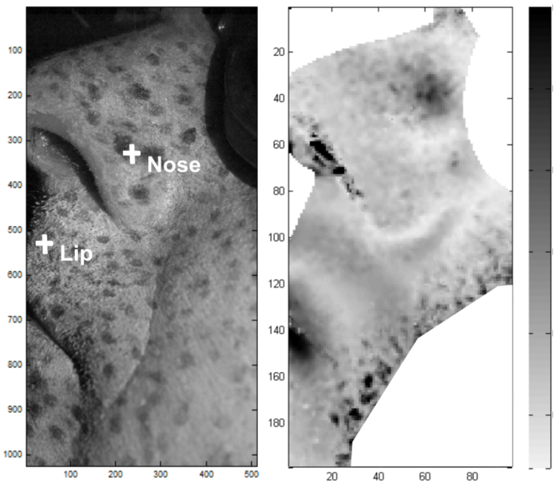

Figure 1. The example of camera image with position of neasured points (left) and the standard deviation of measured vibration (right)

Using camera synchronizing channel segments corresponding with accelerometer and vibrometer records were found. Mean values of differences between maximum and minimum of amplitudes were calculated as absolute values of vibration amplitude. The resulting mean values of upper lip oscillation measured by vibrometer were correlated with mean values of amplitudes measured by high-speed video (HSV) in the direction x and y axes and total values. Analogously the resulting mean values of ala of nose oscillation measured by accelerometer were also correlated with HSV.

For further analysis Bonferroni correction was applied, required P-value 0.05 was divided by the number of correlations (6), therefore the acceptable correlation value was P < 0.0083.

IV. Analysis and Results

A. Correlation between HSV data and accleremoter or vibrometer data

In four voice exercises described above in the part III. C the number of measured phonations with different pitch was 29. Table I shows the results of correlations of measured data. The ala of nose was monitored by accelerometer, the upper lip was monitored by vibrometer. Correlations between these data sets and data gathered by HSV were found.

B. Statistics

Two-way Analysis of Variance (ANOVA) was conducted on vibration amplitudes with the type of vocal tract and pitch. Table II shows the results of two-way ANOVA. The highest effect of both pitch and vocal tract was found on the lip in the y-direction (ALy), Fig. 2 shows the box-plot diagram for the amplitudes of lip vibration in the y-direction for different types of vocal tract.

The results show significant effect of the vocal tract and pitch on the amplitude of oscillation. The vocal tract effect was found the most significant on the lip oscillation measurement in the y-direction, pitch effect was found the most significant on the total amplitude of oscillation measurement and also in the y-direction of oscillation measurement. On the contrary type of vocal tract does not influence amplitudes of the lip and the ala of nose oscillation measurement in the x-direction. Pitch at least influenced amplitude of lip oscillation in the x-direction.

Fig. 3 shows measured amplitudes of the upper lip in pixels in the direction x and y axes of closed brumendo measurement. It is the same time sequence as is depicted on the right side of Fig. 1. Fig. 3 documents complex oscillation of lip surface with phase shift between the peak values of x and y. Measured point proves the vibration in the direction of ellipse as is shown at the bottom part of Fig. 3.

TABLE I. Correlations of Measured data

Location		Ampl.	Ampl. X	Ampl. Y
ala of nose	Pearson rho	0,82	0,68	0,78
	Pval	3,81E-08	5,83E-05	6,09E-07
upper lip	Pearson rho	0,67	0,76	0,54
	Pval	7,37E-05	1,87E-06	0,0023

TABLE II. Results of two-way Anova

	Vocal tract			Pitch		
Par	*df*	*F*	*Prob>F*	*df*	*F*	*Prob>F*
AL	2	8,32	0,0042	11	6,78	0,0007
AN	2	8,54	0,0038	11	8,65	0,0002
ALx	2	1,56	0,2454	11	1,44	0,2585
ALy	2	16,6	0,0002	11	7,69	0,0003
ANx	2	2,35	0,1315	11	4,41	0,0056
ANy	2	8,27	0,0043	11	8,4	0,0002
ANa	2	6,45	0,0104	11	2,94	0,0303
ALv	2	14,29	0,0004	11	3,25	0,0207
SPL	2	7,68	0,0056	11	3,25	0,0206

A means Amplitude, L means lip, N means nos, x and y mean axes¨ directions, a means accelerometer, v means vibrometer

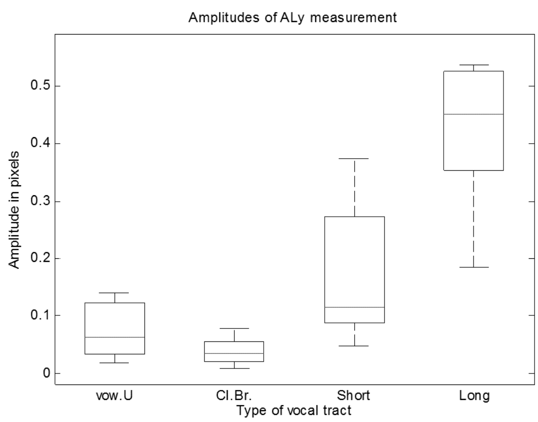

Figure 2. Amplitudes of ALy mesurement

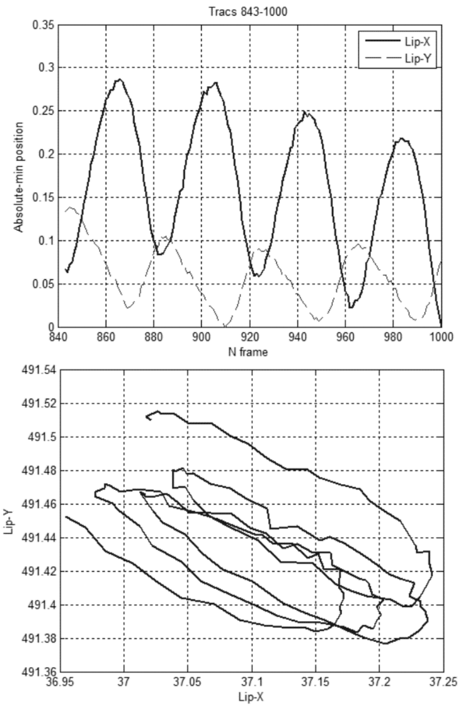

Figure 3. Measured upper lip vibrations in x and y directions during closed brumendo

V. DISCUSSION AND CONCLUSION

Fig. 1 shows positions of measured points used for correlation coefficients calculation. On the right side of the figure the standard deviations of measured total deviations of facial area during closed brumendo measurement for four consecutive oscillations are shown. The results show different values of vibrations amplitudes. The highest measured vibrations are on the mouth area, then in the middle of the upper lip and on the nasal bridge in the middle of the lateral surface of the nose.

Different values of correlation between optical measurement and using of accelerometer or vibrometer point out the fact that facial vibrations are the compound event and facial surface oscillates in all directions. Vibrometer and accelerometer can monitor surface vibration only in one direction. Monitoring using high-speed camera provides measurement in the direction of two axes. Using of two high-speed cameras could make possible vibration measurement in all directions.

Found correlation coefficient values between optical and vibration measurement shows a high level of compliance. All correlation coefficient values complied with Bonferroni correction of required level of statistical significance. The most relevant was the amplitude of vibration measurement of the upper lip. The value of amplitude in the y-direction was more significant than the value of amplitude in the x-direction. The ala of the nose oscillation measurement showed the highest correlation coefficient with vibration measurement by accelerometer in the x-direction.

Statistical evaluation showed the highest effect of both pitch and vocal tract type was found on the lip in the y-direction.

Facial vibration measurement using HSV methods confirmed their relevance with current methods using accelerometers or vibrometers. The crucial advantage of HSV methods we observe is the possibility of simultaneous monitoring of the high area of the face and the possibility of phase oscillation evaluation of individual parts of the face. Using two cameras these methods can be extend to 3D surface measurement, which can be used for the explanation of facial vibration patterns in the specific resonance exercises in vocal education or therapy.

ACKNOWLEDGMENT

This research has been supported by the Ministry of Education, Youth and Sports of the Czech Republic in the Long Term Conceptual Development of Research Institutes grant of the Academy of Performing Arts in Prague: The "Sound quality" project.

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