Title	声帯麻痺による異常声帯振動の病態解析とそのモデリングに関する研究
Author(s)	永沼，宙
Citation	
Issue Date	2008-03
Type	Thesis or Dissertation
Text version	author
URL	http://hdl.handle.net/10119/4327
Rights	
Description	Supervisor:徳田功，情報科学研究科，修士

Research on analysis and modeling of abnormal vocal fold vibrations by vocal cord paralysis

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February 7, 2008

Keywords: Abnormal vibrations analysis, Vocal cord paralysis, Two-mass model, Digital high-speed recording, Parameter estimation.

Voice disorders caused by vocal fold atrophy originate from a complex nonlinear vibration of the vocal folds. Deep understanding of the voice disorders based on a mathematical modeling of the vocal folds may provide an important insight into abnormal vocal fold vibration as well as a good hint for improving the voice surgery. Up to date, various models have been developed to simulate complex vibratory patterns of the vocal folds, ranging from a simple two-mass model to complex multi-mass models. If the simulation of the vocal fold atrophy before and after operation becomes possible, the effect of the operation can be predicted beforehand so as to improve the effect of the surgery. In this research, parameters of the vocal fold model are estimated for digital high-speed recording of vocal fold atrophy.

By using an asymmetric two-mass model, right and left vocal fold tensions, subglottal pressure and glottal area are estimated. Whether the effect of voice surgery is reflected in the estimated parameters is judged by using the data before and after the voice surgery. Based on the results, applicability of the mathematical vocal fold model as a simulator for the voice surgery is discussed.

In this research, we used the glottal waves of seven patients before and after the operation. The glottal waves recorded by the digital high-speed camera. All patients suffer from vocal cord paralysis. As the voice surgery, injection medialization of vocal cords by biologic implants was carried out. In the high speed recording of the glottal waves, the unit of the amplitude is in pixel. The amplitude has been converted into cm for the comparison with the glottal waves generated by the model.

Döllinger *et al.* developed a method for extracting vibration parameters from the digital high-speed camera data by using an asymmetric two-mass model. By using Steinecke-Herzel asymmetric two-mass model (SH model), right and left vocal fold tensions and subglottal pressure are estimated. Therefore, we estimated parameters of SH model from the recorded data of vocal cord paralysis by using Döllinger's method. As a result, the closed phase cannot be reproduced by Döllinger's method. It is necessary to reproduce the change in the closed phase and the glottal area by the operation to aim at the reflection of the effect of operation to the model.

Therefore, we proposed the method of that the presumed parameter added the glottal area and included the closed phase in the cost function. The injection medialization technique intended to narrow the glottal area. It seems that the effect of operation is reflected in the estimated parameters when the closed phase is included in the cost function. The item of the proposed cost function is a fundamental frequency, a power spectrum, and a close period. We use the SH model. The Nelder-Mead algorithm was used to optimize the cost function. As an advantage, because the cost function is optimized without the derived function, it settles easily. The optimization procedure requires suitable initial values. For all combinations of the parameter values (left and right vocal fold tension parameters, subglottal pressure and glottal area), 20 sets of parameter values that give the minimal cost function are collected. Left and right tension parameters obtained from a fundamental frequency of the digital high-speed camera data.

The glottal waves generated by the SH model and the digital high-speed camera data were compared by using the fundamental frequency difference between right and left vocal folds, the phase difference, the amplitude difference, the closed phase and Normalized Amplitude Quotient (NAQ). The NAQ evaluates the strength of the sound.

We compared the estimated parameters. The result shows that the glottal area becomes smaller after the operation than before. Moreover, It is shown that the closed phase increases after the operation more than before as a result by the comparison of the glottal wave forms generated by SH model and the digital high-speed camera data. As a results, the estimated parameters and the closed phase imply that the effect of the voice surgery is appropriately reflected in the estimated parameter values.

Moreover, we proposed two kinds of estimated tension parameters addition methods for the accuracy of the glottal waves to improve generated by the SH model. First method, we assumed that each tension parameter of mass and the spring constant was different values. Second method, each tension parameter of lower mass and upper mass was different values. These tension parameters were separately obtained. The parameters were estimated by using the SH model by whom each tension parameter addition method was applied, and we compared using each method with normal SH model.

As a result, tension parameter addition methods were suggested to reflect the effect of the operation better than the normal SH model. However, tension parameter addition methods did not become a large improvement. As for the reason, the item of the evaluation function is a few.

Future studies included estimating parameters in different fundamental frequency with a right and left vocal fold. When a fundamental frequency is different with right and left, it is necessary to improve the model because the parameter estimation is difficult.