A Vocal Tract Model using Multi-line Equivalent Circuits

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Abstract

The 3-D vocal tract shape has information for phonetic or personal characteristics, and it has an important meaning to study for the relation between the vocal tract shape and the acoustic characteristics. The FEM analysis is a useful tool for the acoustic analysis, but the computational cost is a problem. On the contrary to the FEM modeling, the transmission line model is convenient to evaluate the impedance function without high computational cost. We propose a new multi-line model which is available to represent the multi-channel as liquid sound.

1 Introduction

The FEM analysis is a useful tool for the acoustic analysis, but the computational cost is a problem. On the contrary to the FEM modeling, the transmission line model is convenient to evaluate the impedance function without high computational cost, but the involving the 3-D parameters is difficult because of the one-dimensional model essentially. We propose a vocal tract modeling using a multi-line model to involve the 3-D parameters. The multi-line model can represent the complex shape including branches in the vocal tract, and evaluate the acoustical characteristics for the 3-D shape in the low computational cost. In order to estimate the 3-D shape of the vocal tract from the sliced data of MRI, we propose a new algorithm and evaluate the estimated shape. Using this algorithm, we can extract information about the coordinate of the branch in the vocal tract, and include the information in the multi-line model. We show the computation method using the cascade matrix of circuit theory for the impedance function of the vocal tract from the measurement data.

2 Problem of Numerical Computation for Vocal Tract Acoustics

The FEM analysis is well known method as an analysis tool to get the detailed figure of pressure or velocity pattern in the vocal tract with complex shape. It is very difficult to get the finite element model for this complex shape, and the simulation with the fine mesh is required huge memory or high computational cost. Contrary the line model is based on a equivalent circuit for the acoustic propagation of one dimensional system, and the computational cost is very low. However it has essential problem caused by the one dimensional model.

For example as we see in Fig. 1, the branch position is modeled as only one point, but in the real branch between the two ducts one can see the finite area which is relevant to the cross section of the duct.

Figure 1: Simple Branch model for lines

In this case the approximation accuracy is problem for high frequency region, because the size of cross section of the branch is comparable to the length of quoter of the wave length.

The branch of the vocal tract is appeared in near the glottis as the pyriform sinus or the case of nasal sound and the liquid sound. The FEM analysis for the vocal tract with branch was performed, and it is shown that the low pressure distribution is appeared around the junction [3]. If the model of Fig.1 is as-
sumed, the above distribution cannot be represented because of the one point junction. A new circuit model is required to represent approximately such the distribution on the area of junction.

3 Measurement of Cross Sectional Shape of Liquid Sound using MRI

Software Tool for 3D graphical data

In order to investigate the complex structure of the vocal tract, we used a MRI equipment and developed the software tool for the contour extraction of the image data, the construction of the 3-D shape of the vocal tract and the estimation of the cross sectional area as the acoustical duct. Since it is difficult to obtain the boundary of teeth by using MRI, we employ the technique of teeth crown with a liquid for enhancement of images, and we see this boundary in the image data obtained as in Fig.[2, 3]. All the image is for liquid sound /l/. In the liquid sound /l/ the path of air is appeared in both left and right sides of the tong.

Figure 2: enhanced MRI data 1

The MRI data from measurements are transferred to Tiff format files, and the files are processed on a PC Unix. The software is written by C++ and Xwindow library. The figures [2, 3] are processed image as enhanced contrast data.

As is seen in the figure, the teeth boundary is appeared clearly as white lines. The relation between the tong and the teeth can be seen in the figures. From these enhanced images, we extract the contour of the cross section of the vocal tract by using the tool.

Feature of Cross Section

The several examples of contours extracted are shown in figures Fig.[4,5,6, 7]. The all data are for liquid sound /l/. The contours are numbered from glottal side to the lips, and the distance between each

slices is 5mm. In Fig.4 the window shows menus

Figure 3: enhanced MRI data 2

and the extracted contours from the enhanced images. The extracted contours are very flat shape here. As we see in Fig. [5,6], the cross sectional shape is approximately elliptic (from no.01 to no.07), but from no.08 to no.11 the tong shape is much different from the previous sections. In the ordinal MRI measurement, it is difficult to extract the boundary of the teeth, but our extracted contours show the clear boundary. In the section from no.8 to no.11, the tong make very thin air channel and two or three channels as the upper channel and the side channels with different area size. From the figure we see that the teeth is important manner to make complex shape of the side channels. If we employ the assumption for the tract shape with a mono pipe, it is difficult to evaluate the effect of such the thin channel or multi-channel figure. We cannot ignore the effect including the such figure. The last section from no.13 to no.15 show the lip shape which influences the radiation impedance [1].

Figure 4: Exstrated contours 02(upper),01(lower) and menus
4 Circuit Model Using Multi-line

As mentioned above, we should count the effect of the multi-channel in the vocal tract. Though the FEM analysis is applicable for that figure, but we propose here the circuit model with multi-line. If we make a parallel circuit of the same $N$ circuits as in Fig.9, the input admittance become $N$-times of the original one. The TLM is well known as a comput-

Figure 9: Input admittance for lines

Figure 10: Branch model for lines

If we assume that the frequency is not so high, we can assume the junction of the branch
is connected with several lines as Fig.10 In that figure we represent the boundary condition at the vocal tract wall as slash lines, and that the junction is divided as small section of distribution of propagation wave. In the case of liquid sound as seen in the previous section, we propose a new branch model as in Fig.11. In this figure, the branch is represented in several part, and shows the channel like the upper one of the tong or side channel. The branch model require the new computation method for frequency characteristics.

5 Computational Method for Multi-line Model

As an example of the branch we discuss the case that the tong tip is touching at the hard palate; the closed channel is appeared on the between tong and the hard palate. In this case the infinite impedance is caused by the closing channel. $F_i$ shows the cascade matrix for the transmission line. The matrix for sections from the glottis to the branch is shown as

$$F_g = \begin{bmatrix} A_g & B_g \\ C_g & D_g \end{bmatrix} = \prod_{i=k}^{m} F_i$$

(1)

The matrix for sections from the branch to the lips is shown as

$$F_l = \begin{bmatrix} A_l & B_l \\ C_l & D_l \end{bmatrix} = \prod_{i=1}^{n} F_i$$

(2)

The matrix for the side channel is shown as

$$F_r = \begin{bmatrix} A_r & B_r \\ C_r & D_r \end{bmatrix} = \prod_{i=n+1}^{k-1} F_i$$

(3)

The matrix for the upper channel of glottal side is

$$F_1 = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} = \prod_{i=q+1}^{k-1} F_i$$

(4)

The matrix for the upper channel of lips side is

$$F_2 = \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} = \prod_{i=n+1}^{p-1} F_i$$

(5)

$Y_1, Y_2$ represent the input admittance for the circuit $F_1$ and $F_2$

$$Y_1 = \frac{C_1 + D_1 Y_{1L}}{A_1 + B_1 Y_{1L}}$$

(6)

$$Y_2 = \frac{D_2 + B_2 Y_{2L}}{C_2 + A_2 Y_{2L}}$$

(7)

$$F_r = \frac{1}{B} \begin{bmatrix} A_r & B_r & A_s & B_s \\ C_r & 1 & D_r & B_r \end{bmatrix}$$

Where $C_r = (C_1 C_2) (B_1 + B_2) + (A_1 - A_2) (D_1 - D_2)$, and $B = B_1 + B_2$. Finally we can compute the matrix for the total circuit as

$$F = F_g \begin{bmatrix} 1 & 0 \\ Y_1 & 1 \end{bmatrix} F_r \begin{bmatrix} 1 & 0 \\ Y_2 & 1 \end{bmatrix} F_l$$

(8)

6 Conclusion

We measured the vocal tract shape using MRI data and our software tool, discussed about the cross section for the liquid sound, and proposed the multi-line model for the sound. We also the computational method of the impedance functions for the circuit model.

References


