Study on Phonation Features of Tones in Mandarin*

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ABSTRACT

This paper is concerned with the study of phonation features of tones and diatones in Mandarin. The method of acoustical analysis includes: 1) inverse-filtering, which is used to extract speech source from the speech sound; 2) magnitude calculating of each glottal pulse; 3) parameter extracting, which is used to extract the parameters of fundamental frequency, speed quotient and open quotient. In this study, 4 basic tones in single syllable words, 16 diatones, and 4 diatones, whose second syllable is neutralized, are analyzed acoustically. The result shows: 1) There are differences between the phonation features of male and female speakers. 2) In general speaking, the patterns of F0 are similar with those of OQ. 3) Phonation patterns do exist in the tones and diatones in Mandarin. 4) Phonation patterns can be used to improve the naturalness in the formant speech synthesis.

1. INTRODUCTION

Mandarin is a tone language, in which tones are very important in distinguishing meanings. In the phonetic study of Mandarin tones, researchers usually use the acoustical parameter of fundamental frequency (F0) to model tones and diatones, and many contributions have been achieved (Liu Fu, 1924; Wu Zhongji, 1980; Kong Jiangping and Lu Shinan, 1998).

Along with the development of speech science and technology, the knowledge of phonetics becomes more and more important. For example, in the formant synthesis, such as Klatt88, the tone parameter, F0, can be exactly set, but the tones in synthesized speech are usually not natural, especially in the tones with lower pitch. That means that tone features are not clear both in time domain and frequency domain, though we know that the main acoustical parameter is F0.

In the phonetic study of the minority languages in China, which belong to Sino-Tibetan family, many different phonation types have been found and studied. We find that different phonation types, to some extents, always have relations with pitch or exactly, we may say, with F0. In these languages, different phonation types are significant in distinguishing meanings and the definition of tone quality is discussed. The acoustical and physiological features can also be used to explain the changes and relations in both synchronous and historical aspects. Although phonation types in Mandarin are not significantly important as those in the minority languages, they really appear in different tones and are often used by singers and oral artists. In addition, different phonation types, which are significant in phoneme, have been found in Chinese dialects. From this point of view, F0 always has close relation with different phonations. In the phonation study, many methods have been used, such as laryngography, which is developed by Fourcin (Fourcin, A. J., 1981). With EGG signal, the phonation of tones and diatones in Mandarin has been studied (Kong Jiangping, 1998; Chen Jiayou and Kong Jiangping, 1998).

2. RESEARCH METHOD

The acoustical analysis used in this study includes: 1) inverse-filtering of speech samples; 2) magnitude calculating of each period; 3) parameter extracting, which is used to extract parameters of fundamental frequency, speed quotient (SQ) and open quotient (OQ).

2.1 Inverse Filtering

The method of inverse filtering used in this study is the cascade inverse filtering (Gold and Rabiner, 1968; Klatt and Klatt, 1990). See the following equation.

$$y(nT) = A'x(nT) + B'x(nT-T) + C'x(nT-2T)$$

where *x(nT-T)* and *x(nT-2T)* are the previous two samples of the output, *x(nT)*, and the constants *A'*, *B'* and *C'* are defined by the following equations:

$$A' = \frac{1.0}{A} \qquad A = 1. - B - C$$

$$B' = \frac{-B}{A} \qquad B = e^{(-\pi BW \cdot T)} \cos(2\pi FT)$$

$$C' = \frac{-C}{A} \qquad C = e^{(-2\pi BW \cdot T)}$$

In order to inverse filtering the speech samples, an inverse filtering system has been establised. In this system, there are 5 inverse filters, which are used for the inverse filtering of the 5 formants, and a pair of inverse filters, which are designed for the inverse filtering of nasal formant and anti-formant.There are 2 main steps: 1) initializing the formant central frequency and bandwidth by co-variance LPC; 2) modifying these parameters according to the FFT spectrum, untill the speech glottal source are obtained.

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2.2 Magnitude Calculating

After the speech glottal source has been extracted, glottal opening instant, peak of glottal airflow, the minimal difference of glottal pulse, whose value is defined as *Ee* in the LF model by G. Fant (1985), and glottal closure instant have been marked. *Ee* is extracted as the magnitude of the glottal pulse.

2.3 Calculating of OQ and SQ

The glottal period, opening phase and closing phase are defined in figure 1. See figure 1.

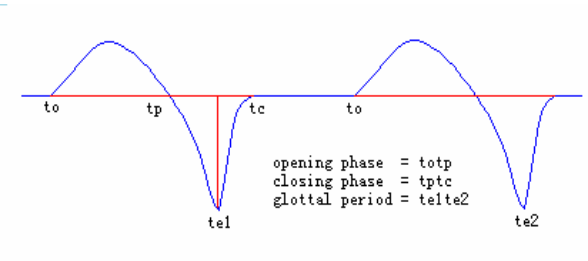

Figure 1: The definitions of glottal period, opening phase and closing phase.

The fundamental frequency, open quotient and speed quotient in this study are defined as follows:

F0=1/glottal period

OQ=(open phase/glottal period) × 100%

SQ=(opening phase/closing phase) × 100%

Since glottal pulse is changing in its shape along with the change of F0, the marks for glottal opening and closing instants will be different in different pulse. In general speaking, there are 3 forms of pulse shape, which reflect the glottal pulse with low pitch, glottal pulse with modal pitch and glottal pulse with high pitch. In this study, the speech sounds of 4 Mandarin speakers are used in this study, 2 male speakers and 2 female speakers. The speakers are all native speakers and speak standard Mandarin.

3. PHONATION FEATURES OF TONES

There are 4 basic single syllable tones. Tone 1 is described as 'high level', which is defined as 55 by the tone letter system of Chao Y.(1930) according to the value of F0. Tone 2 is described as 'rising', which is defined as 35. Tone 3 is described as 'low fall' or 'dim', which is defined as 214, 211 in running speech and 35 before tone 3. Tone 4 is described as 'falling', which is defined as 51.

The parameters of the 4 tones have all been treated by polynomial curve fitting and the coefficients of polynomianl curving fitting for the average phonation parameters are also calculated. The arrangenent of these paramenter contours is that the plot (up left) is F0, the plot (up right) is OQ, the plot (low left) is SQ and the plot (low right) is Ee. Since the limit of pages, only the paramters and the contours of tone 1 are displayed in Figure 2 and Table 1**. See Figure 2 and Table 1.

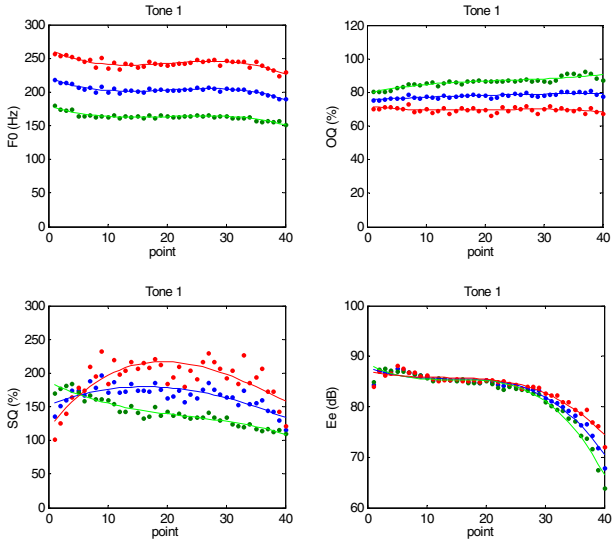

Figure 2: Contours of phonation parameters of tone 1.

F0	-0.031	0.19	-3.5	220
OQ	1.6e-005	-0.0025	0.17	78
SQ	0.00051	-0.12	3.4	150
Ee	-0.00061	0.034	-0.48	88

Table 1: This table gives the coefficients of polynomial curve fitting of F0, OQ, SQ and Ee of tone 1. The names of phonation parameters are in Column 1. The parameters in column 2 and 3 are the curvatures of the 4 contours. The parameters in column 4 are the slopes. The parameters in column 5 are the intercepts.

In each plot of figure 2, there are 3 contours. The contours of F0, SQ and Ee for female are in red or up, the contours of F0, SQ and Ee for male are in green or lower, and the contours of average F0, SQ and Ee of male and female are in blue or middle. The contour of OQ for female is in red or lower, the contour of OQ for male is in green or up, and the contour of average OQ of male and female is in blue or middle.

From the results, we can see that there are differences between the values of male and female. In addition, some contours show the different natures, such as the OQ in tone 2, the OQ in tone 4 and the SQ in tone 4. The OQ in tone 2 is mainly 'falling' for male and 'rising' for female. The OQ in tone 4 is mainly 'rising' for male and 'falling' for female. The SQ in tone 4 is 'falling' for male and 'rising and falling' for female. In figure 2, we can also find that the contours of F0 in the 4 basic tones have the same pattern with those of OQ. The contours of F0 and OQ in tone 1 are both 'level'. The contours of F0 and OQ in tone 2 are 'rising'. The contours of F0 and OQ in tone 3 are 'low falling'. The contours of F0 and OQ in tone 4 are 'falling'. The contours of SQ and Ee are very similar in each basic

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tone. By using the parameters of polynomial curve fitting, all phonation parameters in each tone can be produced automatically.

4. PHONATION FEATRUES OF DIATONES

There are 16 diatones in Mandarin. According to the 4 basic tones, they can be divided into 4 groups. Group 1 has 4 diatones, whose first syllables are tone 1. They are diatone 11, diatone 12, diatone 13 and diatone 14. The coefficients of diatone 11 are given in Table 2. Group 2 has 4 diatones, whose first syllables are tone 2. They are diatone 21, diatone 22, diatone 23 and diatone 24. The coefficients of diatone 21 are given in Table 3. Group 3 has 4 diatones, whose first syllables are tone 3. They are diatone 31, diatone 32, diatone 33 and diatone 34. The coefficients of diatone 31 are given in Table 4. Group 4 has 4 diatones, whose first syllables are tone 4. They are diatone 41, diatone 42, diatone 43 and diatone 44. The coefficients of diatone 41 are given in Table 5. In this section, only the coefficients of polynomial curve fitting of diatone 11, 21, 31 and 41 are displayed for examples.

F0	0.0099	-1	220	0.0076	-0.8	210
OQ	-0.0012	0.24	75	0.0029	-0.24	80
SQ	-0.18	7	110	-0.1	2.7	160
Ee	-0.013	0.38	83	-0.016	0.45	83

Table 2: This table gives the coefficients of polynomial curve fitting of F0, OQ, SQ and Ee of diatone 11. The names of phonation parameters are in Column 1. The parameters in column 2 and 5 are the curvatures of the contours for the first tone and the second tone. The parameters in column 3 and 6 are the parameters of slopes. The parameters in column 4 and 7 are the intercepts.

From the results of group 1, the contour of F0 in tone 4 is 'high level' in the first tone and the F0 of tone 1 to 3 has a slight 'falling'. The contours of OQ in the first tone are 'flat' except that in tone 1. The contour of OQ in tone 1 has a little 'rising'. The contours of SQ and Ee in tone 1 are as same as those in tone 2.

F0	0.0033	-0.66	160	-0.0028	-0.26	200
OQ	-0.0036	0.46	54	0.00094	0.17	70
SQ	-0.094	4.3	70	-0.079	2.8	120
Ee	-0.02	0.76	78	-0.017	0.45	83

Table 3: This table gives the coefficients of polynomial curve fitting of F0, OQ, SQ and Ee of diatone 21. The names of phonation parameters are in Column 1. The parameters in column 2 and 5 are the curvatures of the contours for the first tone and the second tone. The parameters in column 3 and 6 are the slopes. The parameters in column 4 and 7 are the intercepts.

In this group, it can be seen that the patterns of different parameters of diatones are different in this group. In general speaking, the patterns of F0 are similar with those of OQ in the 4 diatones except the pattern in diatone 21. The patterns of SQ and Ee in diatone 21 are the same. The other patterns of different parameters are different.

F0	0.017	-1.9	170	-0.017	0.49	190
OQ	0.012	-0.82	70	0.0084	-0.38	76
SQ	0.026	-1.1	100	-0.12	4.5	110
Ee	-0.0081	-0.0098	85	-0.021	0.63	82

Table 4: This table gives the coefficients of polynomial curve fitting of F0, OQ, SQ and Ee of diatone 31. The names of phonation parameters are in Column 1. The parameters in column 2 and 5 are the curvatures of the contours for the first tone and the second tone. The parameters in column 3 and 6 are the slopes. The parameters in column 4 and 7 are the intercepts.

From the results of group 3, we can see that the patterns of F0 are as same as those of OQ. The pattern of SQ in diatone 31 is as same as that in diatone 32 and the pattern of SQ in diatone 33 is as same as that in diatone 34. The pattern of Ee in diatone 31 is as same as that in diatone 34.

F0	0.0044	-2.7	230	-0.019	0.96	170
OQ	0.0099	-0.49	73	0.0033	0.095	61
SQ	-0.039	0.98	150	0.035	-2.4	140
Ee	-0.016	0.46	83	-0.013	0.25	84

Table 5: This table gives the coefficients of polynomial curve fitting of F0, OQ, SQ and Ee of diatone 41. The names of phonation parameters are in Column 1. The parameters in column 2 and 5 are the curvatures of the contours for the first tone and the second tone. The parameters in column 3 and 6 are the parameters of slopes. The parameters in column 4 and 7 are the intercepts.

In the last group, the pattern of OQ in diatone 41 is as same as that in diatone 42 and the pattern of OQ in diatone 43 is as same as that in diatone 44. The pattern of Ee in diatone 41 is as same as that in diatone 42 and diatone 44.

After analysis of the 16 diatones, there are 15 patterns for F0 , 14 patterns for OQ, 8 patterns for SQ and 5 patterns for Ee. Obviously, the pattern of OQ is less than that of F0, the pattern of SQ is less than F0 and OQ, the pattern of Ee is less than F0, OQ and SQ.

5. PHONATION FEATURES OF NEUTRALIZED DIATONE

There are 4 diatones with neutralized tone in the second syllable. The neutralized tone is called tone 5, whose F0 can be specified according to the tone of the first syllable.

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The 4 diatones are diatone 15, diatone 25, diatone 35 and diatone 45. Here only the coefficients of polynomial curve fitting of diatone 15 are displayed. See Table 6.

F0	0.037	-1.2	200	-0.14	-2.9	210
OQ	-0.0075	0.21	81	-0.0014	-1.1	81
SQ	-0.11	4.7	120	-0.23	1.7	140
Ee	-0.014	0.58	80	-0.13	2	78

Table 6: This table gives the coefficients of polynomial curve fitting of F0, OQ, SQ and Ee of diatone 15. The names of phonation parameters are in Column 1. The parameters in column 2 and 5 are the curvatures of the contours for the first tone and the second tone. The parameters in column 3 and 6 are the parameters of slopes. The parameters in column 4 and 7 are the intercepts.

From the results, we can see that the pattern of F0 and OQ in the 4 diatones are very similar except the neutralized tone in diatone 35. The pattern of SQ in diatone 15 is as same as that in diatone 35, and the pattern of SQ in diatone 25 is as same as that in daitone 45. In addition, the patterns of Ee are the same in diatone 15 and 25, and the patterns of Ee are the same in diatone 35 and 45. After the analysis of the 4 diatones with neutralized tone, there are 4 patterns of F0, 4 patterns of OQ, 4 patterns of SQ and 2 patterns of Ee.

6. CONCLUSIONS

In the study of phonation, there are many methods, which can be used in phonation study, but in the acoustical study on phonation, the most useful method is that of inverse filtering of speech sound. Through the inverse filtering of tones and diatones in Mandarin, We have found that phonations in Mandarin, a tone language, is very important and do exist patterns in tones and diatones. These patterns have been proved important in formant speech synthesis, after some small-scale samples have been synthesized. In this study, since the inverse filtering system and formant speech synthesis system use the same principle, good synthesized samples have been obtained. As for the method of inverse filtering, there are still some problems, which should be further studied and improved, especially the method of how to extracting anti-formant (zeros) and modeling different types of the glottal pulse automatically.

The conclusions are: 1) there are differences between the phonation features of male and female speakers; 2) in general speaking, the patterns of F0 are similar with those of OQ; 3) phonation patterns do exist in the tones and diatones in Mandarin; 4) phonation patterns can be used to improve the naturalness in the formant speech synthesis.

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**Since there is the limit of the pages, the parameters and figures are not all dispolayed in this paper. Researchers, who need them, can send email to the author to obtain all the parameters and figures.