Measurement of phonetic differences in Guangxi dialects

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Abstract. The study of dialect differences plays an important role in the research of linguistics. In the recent years there has been a trend to measure dialect differences with computational models. From the perspective of phonology, a syllables of a Chinese character can be divided into three parts: The Initials, the Finals and the Tone. The Initials are usually composed of consonants, and the Finals are composed of vowels or vowels and consonants. Therefore, as long as the quantitative characteristic of vowels and consonants are described, and the Five-Degree markings method of tones are used, the differences between Chinese syllables can be calculated. We developed a model and applied it to the measure and analysis the differences of dialects in Guangxi. The analysis results accord with empirical data of Guangxi province dialectal subdivisions and this shows the validity of the model.

1. Introduction

Linguistics have been studying dialect differences for a long time[1, 2, 3, 4, 5]. The research can not only support subdividing regions according to dialects [6], but also provide a special perspective for studies on social phenomena such as cultural differences, population migration, and integration of ethnicities [7]. The differences between dialects are prominent in the aspects of phonetic, while the differences in vocabulary and grammar are relatively small [8]. Therefore, the measurement of phonetic differences becomes an important part of dialect research.

The differences of phonetics of Chinese dialect are reflected in their Initials consonant, Finals vowels and Tone, on which many scholars study this problem. Lu Zhiji [9], Yang Dingfu [10] and Xie Jianyou [11] calculated the dialect differences by counting the number of vowels and consonants found in different dialects. These works have laid the foundation for the study of Chinese phonetic differences, but due to the limited technical methods at that time, these studies only made rough descriptions of phonetic differences among dialects, only presenting whether or not the features of each phonetic have appeared. This paper will quantitatively describe the phonetic features of each phoneme based the work above, characterize it use a 3 or 4 dimension vector, and assign the weights of each part to calculate the distance of dialects among different regions.

In respect of the research region, we choose Guangxi Zhuang Autonomous Region (Guangxi Province), which has the largest minority population in China. In Guangxi province, there are 12 ethnicities settle down in the district such as Zhuang, Han, Yao and Miao, etc. In such a social context Guangxi has developed a large number of Chinese dialects nowadays [12]. According to “Language Atlas of China” [6], modern Chinese dialects are divided into ten dialectal areas such
as northern dialect, Hakka dialect, Wu dialect, and Cantonese dialect, while Guangxi province includes the southwest Mandarin dialect, Cantonese dialect, Xiang dialect, Hakka dialect, Min dialect, Ping dialect six categories, even some unknown native languages. Therefore, Guangxi province are called “the mine of languages” by many people, and this shows great research value [11].

2. The Model

Traditional phonology divides a Chinese syllable into three parts: initials consonants, Finals vowels and tone, so the differences of Chinese pronunciation among regions are reflected in these three parts. We characterize these parts respectively.

2.1. Initials Consonants

In most cases, the Initials are consonants at the beginning of the syllables. There are also some syllables without consonants, which are called zero consonants. Therefore, the initial consonants differ in the consonant pronunciation. Consonants are the sounds generated in the mouth or pharynx as the air flow is obstructed. The pronunciation features can be described from the four aspects. They are place of articulation, obstruction characteristics, airflow intensity and loudness.

The place of articulation refers to the part where the airflow is obstructed when pronouncing it. There are roughly 11 areas from the lips to the throat [13], each of which place is assigned a number with the sequence (starting from 1/11 and with 1/11 increment) accordingly. The place of articulation and the characteristic value are shown in Table 1.

| Place of articulation | Bilabial | Labiodental | Dental | Alveolar | Post-alveolar | Retroflex |
|-----------------------|----------|-------------|--------|----------|--------------|-----------|
| characteristic value  | 0.091    | 0.182       | 0.273  | 0.364    | 0.455        | 0.545     |
| Place of articulation | Palatal | Velar       | Uvular | Pharyngeal | Glottal      |           |
| characteristic value  | 0.636    | 0.727       | 0.818  | 0.909    | 1             |           |

The pronunciation method refers to the status of the throat, mouth, and nasal control mode when pronouncing the syllable. Nine categories can be divided into according to the extent of the obstruction[13]. The assigned values are shown in Table 2.

| Pronunciation methods | Plosive | Affricate | Nasal | Trill | Tap/Flap |
|-----------------------|---------|-----------|-------|-------|----------|
| characteristic value  | 0.111   | 0.222     | 0.333 | 0.444 | 0.556    |
| Pronunciation methods | Lateral | Lateral Fricative | Fricative | Semivowel |
| characteristic value  | 0.667   | 0.778     | 0.889 | 1     |

According to whether there are air supply or airflow strength, two categories can be divided into. No air supply condition is assigned 0.333, and the existence of air supply is assigned 0.667, while the condition of possessing no trait should be assigned 1.

According to whether there exists the vibration of the vocal cords, voiceless and voiced consonants can be characterized. These two categories have significant differences in loudness. The voiceless consonant and the voiced one are assigned 0.33 and 0.66 respectively (the vowel is the loudest, so it should be assigned 1).

For any consonant, four values can be used to characterize their pronunciation features. For example, the phoneme /m/ can be described as the vector (0.091, 0.333, 1, 0.667). For zero initials, the four dimensions should be set to 0.
2.2. Finals Vowels
The Finals refers to the vowel part usually at the end of a syllable or the combination of the vowel and consonants, and it can be divided into rhyme head, rhyme body and rhyme tail. The rhyme head and the rhyme body are composed of vowel, while the rhyme tail is made up of vowels or consonants. Therefore, as long as we characterize the vowel pronunciation features and combine with the consonant pronunciation features discussed in the previous section, we can characterize the differences of Finals vowels. Vowels are unobstructed pronunciation, but they are still restrained by airflow during pronunciation. Their vocal characteristics are mainly investigated from three aspects: the position of the tongue (the upper/lower side, the front/back side in the mouth), and the roundness of the lip.

According to the position of the tongue during pronunciation, 7 levels of the vertical height are categorized from the most upper side to the lowest side [14]. The heights position and their characteristic value are shown in Table 3.

Table 3. Tongue position and its characteristic value.

| Tongue position | Highest | Higher | High | Middle | Low | Lower | Lowest |
|-----------------|---------|--------|------|--------|-----|-------|--------|
| characteristic value | 0.143   | 0.286  | 0.429| 0.572  | 0.715| 0.858 | 1      |

The location of the tip of the tongue can be divided into three categories: front vowel, middle vowel, back vowel [14]. Their characteristic values are shown in Table 4.

Table 4. Anterior and posterior tongue and its characteristic value.

| Anterior and posterior tongue | Front | Middle | Back |
|-------------------------------|-------|--------|------|
| characteristic value          | 0.333 | 0.666  | 1    |

The differences of the lip roundness cause the different shapes of the resonator, forming a variety of vowel-specific sounds. The degree of the roundness of the lip can be divided into 7 types [14], the characteristic values of which are shown in Table 5.

Table 5. Lip roundness and its characteristic value.

| Lip roundness | Open | Near-Open | Open-Mid | Mid |
|---------------|------|-----------|----------|-----|
| characteristic value | 0.143 | 0.286 | 0.429 | 0.572 |
| Lip roundness | Close-Mid | Near-Close | Close |
| characteristic value | 0.715 | 0.858 | 1 |

The phonemes used as rhyme head and rhyme body are vowels, and they can be characterized by the above three features. The rhyme tail may be vowel or consonant, which can be characterized by seven features, and the first three parts are used to describe the vowel, and the last four are used to describe the consonant. Therefore, we need a $3 + 3 + 7 = 13$ dimension vector to describe a complete Finals vowel. For Finals lacking rhyme head or rhyme tail, the lacking parts should be set to zero. For example, /uan/. The rhyme head is /u/ would be $(0.143, 1, 1)$, the rhyme body /a/ would be $(1, 0.333, 0.286)$, and the rhyme tail /n/ would be $(0.364, 0.333, 1, 0.667, 0, 0, 0, 0)$. Another example is /ian/, the rhyme head /i/ would be $(0.143, 0.333, 0.143)$, the rhyme body /a/ would be $(1, 0.333, 0.286)$, and the rhyme tail /u/ would be $(0, 0, 0, 0, 0, 0.143, 1, 1)$. 

3
2.3. Tone
The tone refers to the super segmental phoneme attached to a syllable, mainly shows the pitch of a syllable. The tone system of modern Chinese dialects is more complicated than that of Mandarin. Most areas south to the Yangtze River have more than five kinds of tones. For example, in Nanchang county of Jiangxi province there are 13 kinds of tones. Therefore, differences among tones can hardly be described using four tones in Mandarin. In this paper, Zhao Yuanren’s Five-Scale Marking Method is deployed. This method uses two or three integers ranging from 1 to 5 to represent a tone. For the 2-digit tone, we insert the mean value of these two numbers into the middle of them, so as to unify all representations into 3-digit. The middle tone serves as the dividing line, and the tone is divided into two parts. In this case, a tone has five possible scenarios: flat, rise, fall, rise-fall and fall-rise. In order to describe the pitch and tone characteristics, we use the tone 3-digit representation and the slopes of two tone sections to characterize a tone. Considering all five values range from 1 to 5, We divide this 5-dimensional vector by 5 so that the characteristic values of both the initial consonant and the final vowels are between 0 and 1.

For example, if a certain tone representation is [1, 5], it should be regularized as 3-digit format as (1, 3, 5). Both the slope of the first segment and the second segment are 2. The five-dimension representation should be (1, 3, 5, 2, 2). After regularization and normalization, (0.2, 0.6, 1, 0.4, 0.4) can be obtained. Another example is a tone value of (2, 4, 3), its final five-dimension representation is (0.4, 0.8, 0.6, 0.4, -0.2).

2.4. Measuring the phonological differences
The Euclidean Distance is used to calculate the differences of initial consonant, finals vowels, and tone in different regions respectively. For example, the initial consonant of the Chinese character $C$ may have different pronunciation in different places, but all of them can be described as a four-dimension vector based on their phonetics. Calculating the Euclidean distance between these four-dimension vectors, a distance matrix $D_C$ can be obtained, where

$$D_C(i, j) = \sqrt{\sum_{k=1}^{4} (S_{C,ik} - S_{C,jk})^2},$$

where $i, j$ are the region ID, while $k$ is the feature ID. Selecting the initial consonants of $m$ Chinese characters, and the distance matrices $D_1, D_2, ..., D_m$ can be obtained. Differences of the initial consonants in different regions $i$ and $j$ can be calculated by $D(i, j) = \sum_{n=1}^{m} D_n(i, j)/m$. The calculations in finals vowel and tone are similar to initial consonants. Given a certain weight to initials consonants, finals vowels and tones, we can get the total difference between all regions.

3. Data and Results
3.1. Data Source
The data of this paper comes from “Linguistic Atlas of Chinese Dialects (Phonetics)” [15]. Initials consonants of 71 Chinese characters, finals vowels of 101 Chinese characters and tones of 9 Chinese characters are collected.

There are 930 dialect points were set in the book, and 66 of which locate in Guangxi province. There are 111 county-level regions in Guangxi province, and they are categorized into the 66 dialect points according to the existing dialect division.

3.2. Results
Following the above instructions, distance matrices of initial consonants, vowels, and tones are calculated between 66 dialect points. Hierarchical clustering results of the three distance matrices are shown as Figure 1. We divided all the counties into 7 groups based on the clustering.
results. The same color in the cluster plot and map represents the same category. Because the classification results of different clustering plots are inconsistent, it is inconvenient to make comparisons.

![Image](image-url)

**Figure 1.** Initials consonant, Finals vowels and Tones Clusters of 66 Representative Points in Guangxi province.

It is clearly shown that data has been divided into several categories in all three figures, indicating that the differences between Guangxi dialects are significant. It is consistent with the truth that Guangxi province has a wide range of dialects.

the 111 county-level regions which are represented by the 66 dialect points are projected on the map according to the clustering results, and we can clearly see the aggregate situation of different dialects. It is shown in Figure 2.

![Image](image-url)

**Figure 2.** Initials consonant, Finals vowels and Tones geographic division of 111 counties in Guangxi province.

As can be seen from Figure 2, the clustering patterns of the initials consonants and the vowels are similar. However, the geographic pattern of tones distribution is scattered and has no obvious pattern in this region, except the southwest Mandarin dialect.
The Final is more important than the initial and the tone, but the vector which denotes the final is larger than others. So we set the same weights for the three parts of a syllables, and the distance matrices of total difference between regions can be calculated. Figure 3 shows the clustering result and the map.

![Cluster and map](image)

**Figure 3.** The clustering results and geographic distribution of total difference between regions of Guangxi province.

The clustering results of the total difference are similar to those of the finals vowels. The more obvious ones are the southwest Mandarin dialect, the northeast Xiang dialect, the east Cantonese region, and the middle region mainly popularized Mandarin and few Cantonese. The clustering results significantly distinguish the dialect area. As for the Guiliu Mandarin regions, the model also distinguishes two to three categories, and it is useful for further studying in dialectal subdivisions.

4. Conclusion and Discuss
The results the clustering analysis of dialect differences in different areas of Guangxi province accord with the existing dialect subdivisions, and this shows the validates the model. Also, the model can also provide a basis for dialect division.

Due to the difficulty of data obtaining and limited samples are selected, therefore the results are not precise. The clustering results still are not exactly the same as the existing partition. In addition, there are imperfections in the model when describing dialects in some areas. For example, in some dialects there are double vowels as rhyme body and double consonants as the initial consonants. This model can only deal with these problems in a simplified way, we mainly use the primary consonant or vowel and adjusting it according with the second consonant or vowel. We will improve these two deficiencies in the future work.

**Acknowledgement**
This work was supported by the National Social Science Fund of China under Grant No. 14BSH024.
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