Goertzel Algorithm Based on Matlab Platform System Simulation for Listening Dial Tone Recognition Research

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Abstract: In order to improve the security of using mobile phones and prevent the theft of mobile banking passwords, this paper makes a deep research on the recognition technology of listening dial tone based on Goertzel algorithm of Matlab platform system simulation. Goertzel algorithm is the most classical and practical method to estimate the power spectrum of Dual Tone multi-frequency (DTMF) signal. DTMF dialing system has the advantages of convenient frequency domain analysis and strong anti-interference ability. The algorithm only estimates the power spectrum at two specific frequency points of DTMF signal, and it can deduce the key value from the corresponding relationship of frequency array on the keyboard.

1 INTRODUCTION

Nowadays, smart phones have been completely integrated into our daily life. We frequently tap the mobile phone keyboard, input the phone number, input a variety of passwords or verification code, edit wechat or SMS, operation of online banking, online shopping, often hear the "du tick" button sound, all of these voices are potentially telltale. There are many places in real life where secrets can be divulged. For example, when interviewing public figures on television and audio media, be careful not to play the dialing sound as well. When we usually use mobile phones to make calls, we must pay attention to whether someone is recording the phone number or password, otherwise it is easy to restore out, causing serious hidden dangers. To prevent password leakage, the phone banking system often changes the tone when entering your password to make the dial tone sound strange, so that no one can identify your dial tone.

The Dual Tone multi-frequency (DTMF) signal is used to send commands to the switch. When we press a key on the phone keyboard, two different frequencies of sound are emitted simultaneously, which are converted into electricity for analysis. Through some software means can restore the number key tone, and then resolve the number (Yeh, 2019; Siddhant, 2020).

A complete telephone keypad is shown in Figure 1, with 10 numeric keys and 2 character keys. According to ITU recommendations, each number or character is transmitted by using a combination of two single-frequency signals. Therefore, the signal corresponding to each key on the keyboard can be expressed as:

$$X(t) = A\sin(2\pi f_L t) + B\sin(2\pi f_H t) \qquad (1)$$

In this equation, where f_L and f_H respectively represent the frequency values corresponding to the row and column where the key is located. The frequency values marked on the 4 rows 697 Hz, 770 Hz, 852 Hz and 941 Hz, which constitute the low-frequency group, and the frequency values marked on the 3 columns 1209 Hz, 1336 Hz and 1477 Hz, which constitute the high-frequency group.

The corresponding relationship between keyboard number and frequency is shown in Figure 1.

The values of these frequencies are specially designed: A. These frequencies are within the audible range of a person, so that when a key is pressed, a person can hear it; B. None of these seven frequencies is a multiple of any of the other frequencies; C. No combination, addition, or subtraction of any two frequencies is equal to any other frequency. Therefore, these features not only simplify the decoding of dual-tone multifrequency signals, but also reduce the probability of misdetection of dual-tone multifrequency signals.

According to the regulations of the international telegraph and telephone advisory committee, it is required to transmit a keyboard number or symbol every 100ms, and the duration of the audio signal

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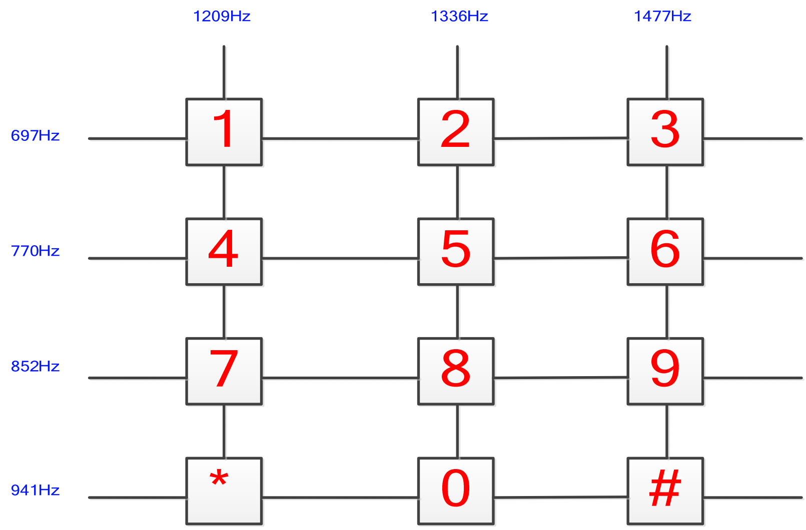

Figure 1: Frequency array of telephone keypad.

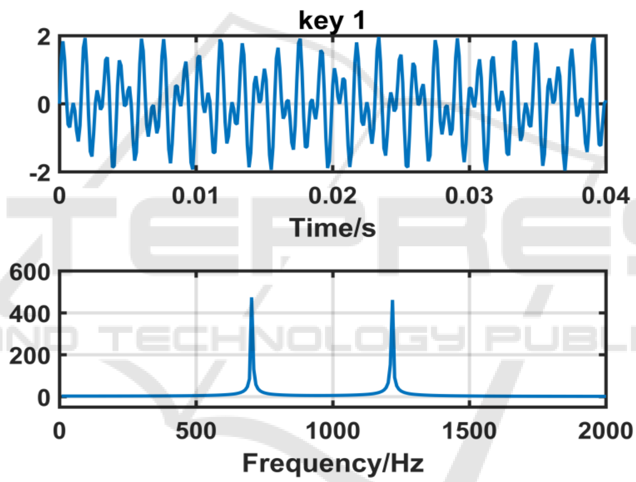

Figure 2: Time-domain and frequency-domain waveforms of key 1.

representing the number must be 45 ~55ms. In order to distinguish between two consecutive key numbers, the rest of the time during the 100ms should be silent (no signal) and the sampling frequency of the telephone signal should be 8kHz. As long as you are familiar with the time-frequency transformation relationship of signal processing, it is easy to see the corresponding frequency value of different time periods, and then according to the principle of DTMF signal, you can immediately deduce the key value.

In other words, the DTMF signal is converted into the frequency domain through Discrete Fourier Transformation (DFT), and then the energy of each frequency point is determined in the frequency domain. Through matlab simulation, Figure 2 shows the time-domain waveform and frequency-domain waveform of key 1. It can be seen intuitively that button 1 is actually composed of two single-frequency signals (697Hz and 1209Hz).

Fig. 3 shows the time-domain waveform and frequence-domain waveform of keys 0-9. It can be seen intuitively that each key is actually composed of two single-frequency signals. The spectral amplitude of DTMF signal is very large at high and low frequencies, and almost zero at other frequencies. DTMF signals are converted into discrete time series, and then DFT is performed to detect the two largest frequencies of the amplitude spectrum. The encoding and decoding of DTMF signals realized in this paper is an ideal situation. In practice, DTMF signals will be aliased and have a lot of noise in the transmission process, and the frequency components of signals cannot be determined simply by calculating the amplitude at a fixed frequency.

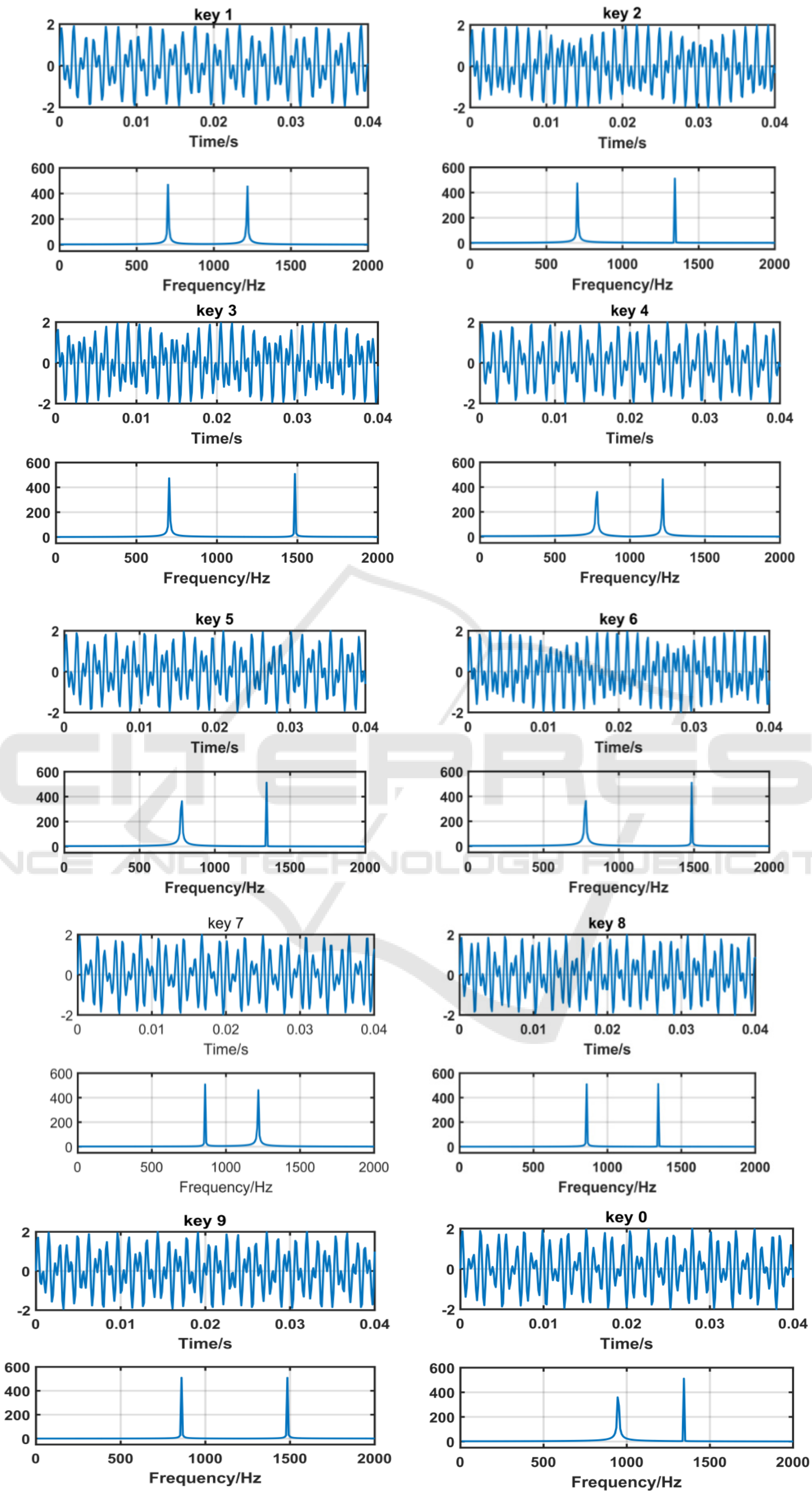

Figure 3: Time domain waveform and frequency domain waveform of keys 0~9.

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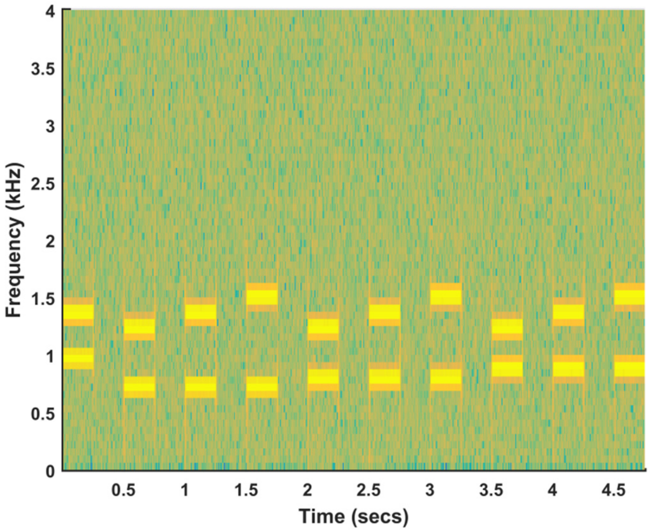

Figure 4: Time-frequency diagram of keys 0-9.

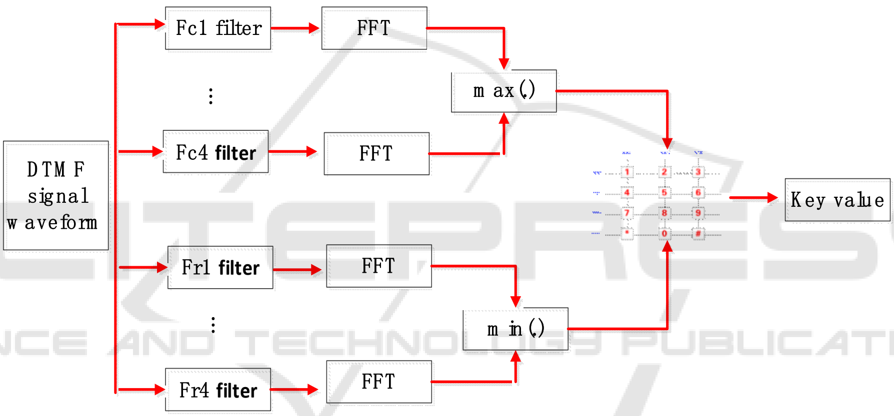

Figure 5. Filter method to identify key values.

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In Figure 4, the time-frequency diagram of dial tone 0-9 is given. In order to better simulate the real situation, the simulation program also introduced two simulation parameters in the source code, namely, dialing interval time (BLK) and transmission noise. As can be seen from the results in Figure 4, keys 1,2 and 3 have the same low-frequency signals (697Hz), while their high-frequency signals rise one by one. The frequency transformation relationship of other keys is similar (Getu, 2015; Porterfield, 2020).

Direct calculation of DFT requires a large amount of calculation, while DTMF signal detection only needs to calculate the spectrum of a few frequency points. Therefore, engineers usually use filter method or Goertzel algorithm to complete the detection of DTMF signal.

2 FILTER RECOGNITION AND SIMULATION RESULTS

The principle of filter method to identify keys is shown in Figure 5. The most critical step of this method is to design 7 bandpass filters, and the center frequency of each bandpass filter corresponds to each frequency point of the low/high frequency group. The dial-tone numbers to be identified (DTMF signal waveform) are passed through the 7 bandpass filters in turn. Theoretically, only the signals whose frequency components are consistent with the center frequency of the filter can pass through. The low/high frequency serial number can be determined by detecting the one with the most energy at the output end of the filter. Finally, the key value can be inversely deduced by the corresponding relationship

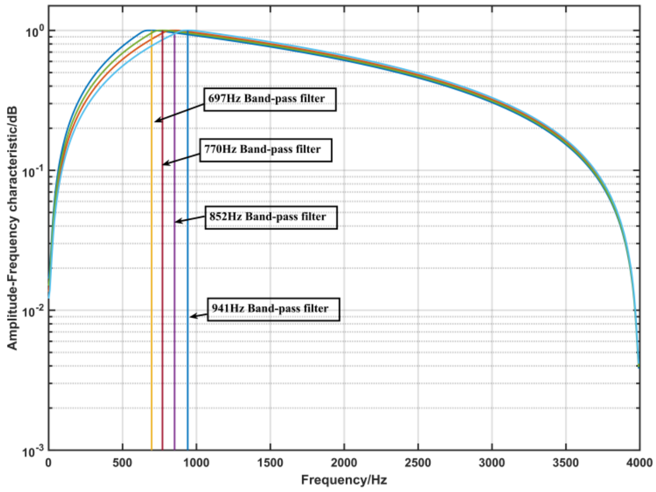

Figure 6: Comparison of amplitude-frequency characteristics of bandpass filters.

of the frequency array on the keyboard.

The input value (Dial Number) is arbitrarily changed to different key values on the telephone keyboard, and the estimated value (key number) is checked one by one. We found that the filter method could not achieve 100% accuracy in identifying a single key value. The recognition effect is sensitive to input signal duration, Fast Fourier Transform (FFT) points and filter order. The bottleneck of filter recognition is that the amplitude-frequency characteristics of bandpass filters are not ideal.

Figure 6 shows the amplitude-frequency characteristics of bandpass filters with center frequencies of 697Hz, 770Hz, 852Hz and 941Hz respectively. In the source code, a method based on frequency sampling is used to design digital filters. As can be seen from Figure 6, the passband parts of the four bandpass filters are all overlapped together, and the single-frequency signals of 770Hz, 852Hz and 941Hz can mostly pass the bandpass filter of 697Hz. In other words, 697Hz bandpass filter is not ideal for 770Hz, 852Hz, and 941Hz single-frequency signals

3 GOERTZEL ALGORITHM AND SIMULATION RESULTS

In theory, DTMF signals only have energy at two fixed frequency points, how to estimate these two frequencies accurately and efficiently is the key to identify dial tone. For the traditional spectrum estimation method, it obtains the estimation results of all frequency points through a frequency range, while for THE DTMF signal, we only care about the power spectrum estimation values at the seven fixed frequency points.

Goertzel algorithm is the most classical and practical method to estimate the power spectrum of DTMF signal. The algorithm only estimates the power spectrum at specific frequency points of DTMF signal. This algorithm makes full use of the periodic characteristics of sequence W_N^k to reduce the computation of DFT.

The calculation formula is as follows:

$$y_k(n) = x(n) + W_N^{-k} y_k(n-1), 0 \le n \le N \quad (2)$$

In the equation, $W_N = \mathrm{e}^{-j2\pi/N}$, N is the number of sampling points, and k is the serial number vector of frequency points to calculate DFT. The computation amount of Goertzel algorithm in application is determined by N value. The larger the calculated N value is, the longer the sampling sequence is. In the case that fs has been determined (8000 in this paper), its signal has stronger frequency resolution and bring longer delay. Therefore, the selection of sampling points N depends on the frequency resolution required by the system. If the value of N is too small, adjacent audio will fall into the same detection window during signal detection and it cannot be distinguished, resulting in misjudgment; if the N value is too large, it not only increases the useless calculation amount, but also causes the delay to increase. Therefore, when the N sampling points are finished, the amplitude judgment of the specified frequency of the signal can be completed, which greatly improves the real-time performance of the system. Goertzel algorithm only calculates the Fourier component of one frequency point at a time. In this paper, N is 205 (Vasu, 2019; Slekas, 2017; KULAÇ, 2015; Onchis, 2014).

As can be seen from Figure 7, the lower signal.

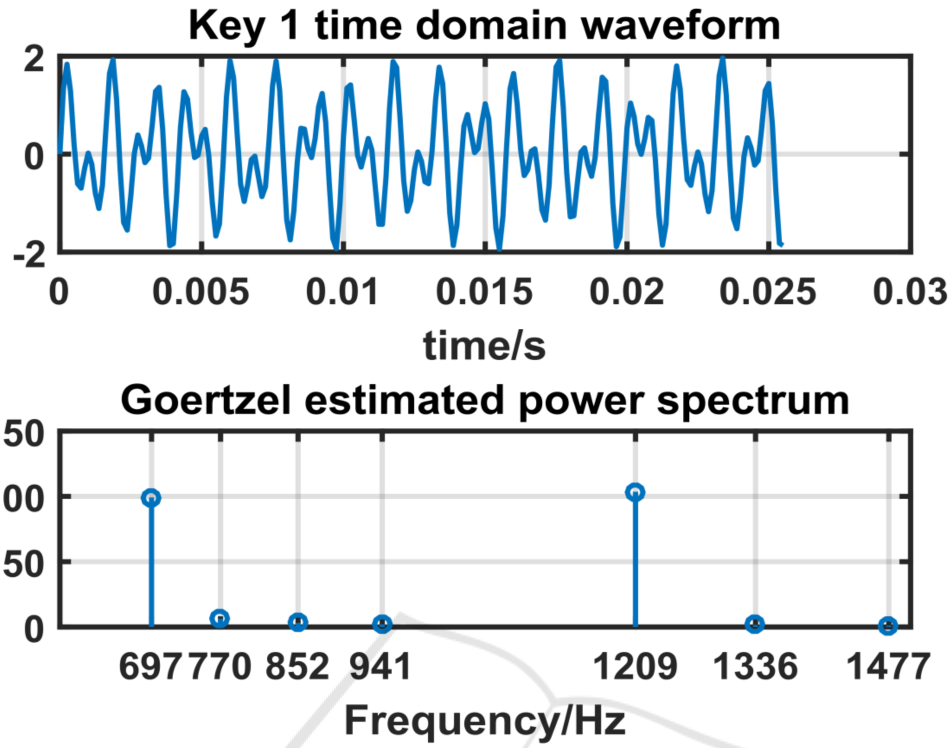

Figure 7: Power spectrum estimation of DTMF signal using Goertzel algorithm (Key 1).

on the left is the frequency component of 697Hz signal, and the other one is 1209Hz signal. The Goertzel algorithm calculates only the frequency amplitude for the specified audio 697Hz. It can be seen from the figure that the power difference between audio signal and background noise is quite large, which is also the basis for judging the existence of audio by threshold method.

As can be seen from Figure 8, Goertzel algorithm only estimates the power spectrum at the 7 frequency points given in advance (only 7 frequency values are needed to represent pure digital keys). At this point, only the frequency points corresponding to the two largest energy values need to be detected, and the key value can be derived from the corresponding relationship of frequency array on the keyboard. Through this method, some important operation keys of users can be recorded, and then the recording data can be detected in the time domain, and then the effective area is converted to the frequency domain for digital classification by Goertzel algorithm, and all key data of users can be obtained by comparing with the DTMF coding table.

Using Goertzel algorithm to identify mobile phone numbers, the recognition effect is much better than filter method, and has certain anti-interference ability to transmission noise. It should be noted that the program directly divides the dial tone of mobile phone into 10 DTMF signals for power spectrum estimation, eliminating the process of voice signal endpoint detection, which is essential in practical application, in addition, when the signal length is extended, the calculation amount of DFT will also increase. However, because DTMF signal detection does not care about the phase information of the spectrum, but only the amplitude information of the spectrum, the Goertzel algorithm only needs N iterations to quickly calculate the amplitude of the spectrum. In essence, Goertzel algorithm is a fast calculation of DFT, but it can selectively calculate DFT values at individual frequency points, so as to avoid the waste of memory and computing resources (Pediredla, 2018; Mahmooda, 2013).

4 CONCLUSION

In this paper "Goertzel algorithm based on Matlab platform system simulation for listening dial tone recognition research", introducing how to use the combination of two single frequency signals to simulate telephone dial tone. This paper based on the DTMF signal waveform infer the key value by estimating the frequency value.

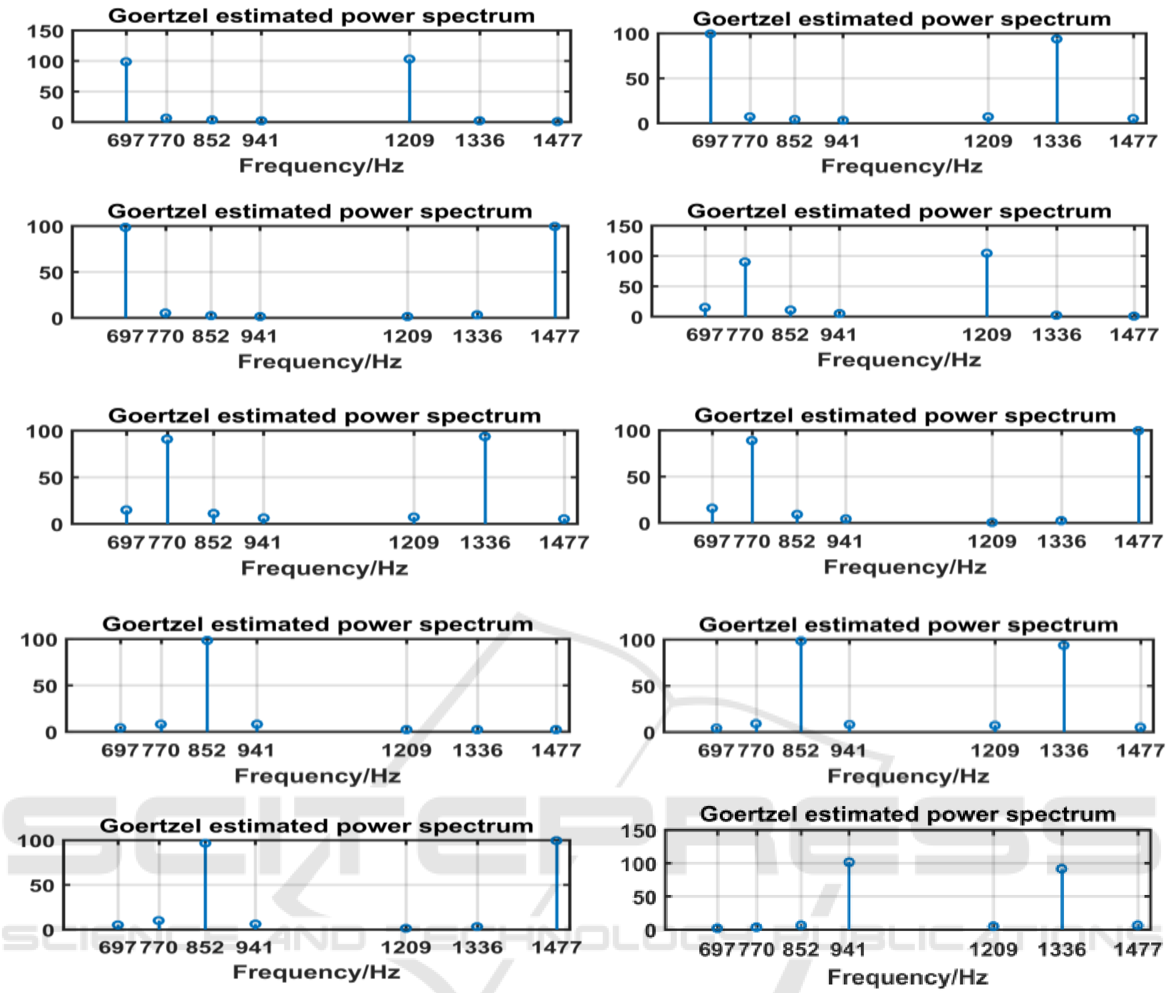

Figure 8: Power spectrum estimation of DTMF signal using Goertzel algorithm (keys 0~9).

Dual-tone multi-frequency dialing system is a typical signal processing system, which can realize the generation, detection and recognition of dual-tone multi-frequency signals. Goertzel algorithm only calculates the spectral components corresponding to a single frequency, which simplifies the calculation of phase in signal detection, so the calculation amount is simplified. Goertzel is more complex for covering the full spectrum, but it is more efficient for a single frequency, making it suitable for a variety of small processors and embedded devices. For audio detection, Goertzel algorithm can use recursive method to start calculation while storing data, saving a large number of storage units, eliminating the delay required by data collection, and improving the real-time communication. In terms of hardware cost and computational efficiency, Goertzel algorithm is superior not only to traditional independent recognition methods, but also to software decoding schemes using DFT.

To sum up, Matlab platform can generate and detect DTMF signal well. Goertzel algorithm is a feasible method to calculate sequential DFT and detect DTMF and calculate input numbers.

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