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DTMF Generation and Detection

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Abstract

Dual-tone multi-frequency signal has been widely used in the modern communication systems like during call setup in mobile communication for transmitting numbers from mobile station to base station. This paper gives a de tailed analysis of the characteristics of the dual tone multi-frequency signal and the method of an analyzing the dual-tone multi-frequency signal using a software. This paper analyzes generation and detection of dual-tone multi-frequency using three methods namely correlation scheme, Fast Fourier Transform and Geortzel algorithm. This paper further compares between these methods on the basis of their computational efficiency, immunity towards noise and accuracy. Computational Efficiency is determined based upon the number of arithmetic operations required for detection. Noise immunity is considered by adding random noise for different signal to noise ratio. This paper also provides a MATLAB simulation of modified DTMF generator with added features of redialing, other line activation and alphanumeric keys using key multiplexing. The paper also provides a simulation of key-multiplexing where multiple functions are assigned to a single key. Hash key is used to facilitate this toggling between functions. These dual-function keys can be further used to append additional functions like alphanumeric keys, speed-dials, etc.

Index Terms: DTMF, FFT, Correlative Scheme, Geortzel algorithm.

Introduction

DUAL-TONE multi-frequency signal is invented by Bell Labs, with a purpose to auto-complete the long distance calls. It is used to send or receive numbers by DTMF signal, whether telephone or mobile phone. By sending voice frequency numbers, the condition of occupying abundance communicate channel can be avoided, and a lot of time can be saved than pulse mode. A DTMF (dual tone multiple frequency) codec incorporates an encoder that translates key strokes or digit information into dual tone signals, as well as the decoder detecting the presence and the content of incoming DTMF signal. Each key on the keypad is uniquely identified by its row and column frequency as shown in the Fig. 1

Typical DTMF frequency ranges from approx. 700 Hz to 1700 Hz with a sampling frequency of 8 kHz.

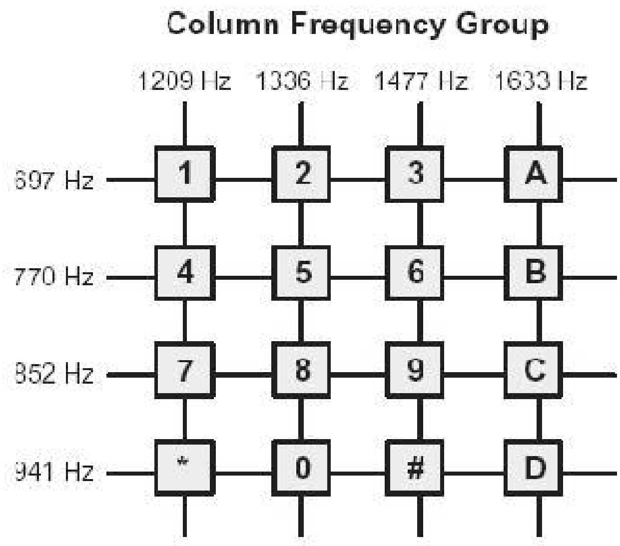

Figure 1: Touch-Tone Telephone Keypad: A row and a column tone is associated with each digit.

Simulation of the DTMF Generator

Mathematical Analysis

A DTMF signal is superimposed by two frequencies audio signals. Each pair of such audio signal represents only one number or one symbol. The production of DTMF signals is two different frequency sine wave forms after stack. A basic DTMF telephone layout consists of 16 keys ten number keys are 0.9, six function keys are 'star', 'hash', A, B, C, D. As per the CCCIT suggestion 697Hz, 770Hz, 852Hz, 941Hz are considered as lower frequency group while frequencies 1209Hz, 1336Hz, 1477Hz, 1633Hz as the high frequency group. Thus, 16 keys can be uniquely denoted by pair of key selected from each group. The signal generated can be mathematically represented as $x_a t$.

$$x_a(t) = A_1 \sin(2\pi f_l t + \varphi_1) + A_2 \sin(2\pi f_h t + \varphi_2) \quad (1)$$

Here A_1 and A_2 represent amplitudes, φ_2 and φ_2 represent the initial phases of corresponding signal while f_l represents of low-frequency group and f_h represents a frequency of high-frequency group. As the computer cannot handle analog signal, DTMF signal is sampled using discrete sampling signal of appropriate frequency(f_s) , sampling interval $T = 1/f$, by (1) ,we can get sampling signal of DTMF as shown below:

$$x(n) = A_1 \sin(2\pi f_l\, n/f_s + \varphi_1) + A_2 \sin(2\pi f_2\, n/f_s + \varphi_2) \tag{2}$$

For an integral value of n, $x(n)$ expresses the amplitude of the first n-sampling time interval (T) signal. In order to analyse conveniently,we take $A_1 = 1, A_2 = 1, \varphi_1 = 0, \varphi_2 = 0$ and sampling frequency f_s = 1 kHz.

Software synthesis

GUI tools can be used to simulate a telephone dial-up panel, mapping DTMF signals subject to telephone key board matrix. Along with the familiar keys, 'star', 'hash', and 0-9 numbers, the proposed panel also consist of extra features like 're-dial', 'dual-line activation', 'dial', and 'end'. The simulated panel also provides a facility to use 'hash' key as alpha/num mode selector. Fig 3 shows the simulated panel.

As shown in Fig. 3, the Modified Panel consists of 16 keys with various functions assigned as follows.

- 0-9/A-J: Alpha-numeric keys, will dial alphabets or numbers depending upon the mode selected.
- Star: Dials Star
- Hash: Is used to select the alpha/numeric mode. By default numeric mode is selected. Pressing 'Hash' one time will cause the dial-up to enter the 'Alpha' mode till 'Hash' is pressed one more time.
- OK: Is used to dial.
- R: Redials.
- C: Activates another line for use.
- E: Ends the call.

The decoding algorithm of DTMF

Due to DTMF signals cannot be identified by sampling time signals, we can analyze and identify from another angle, that is, analyzing DTMF signals from the angle of frequency domain.

Fast Fourier algorithm

Using discrete Fourier transform formula, the time sampling signals length of N , x(n) can be transformed into discrete frequency domain signals X(k), the length of N, too [2]. (Because FFT algorithm is already quite mature, and the limitation of the length of the paper, here does not elaborate on discrete Fourier transform, you can refer to the digital signal processing books if you are interested in it.

$$x(k) = \sum x(n) W_N^{nk} \quad 0 \le k \le N-1 \tag{3}$$

The Goertzel algorithm

The Goertzel algorithm is a kind of linear filter group algorithm to calculate DFT in essence. The advantages of the Goertzel approach over other algorithms are : 1) it is computationally more efficient, and 2) the value of the DFT can be computed at any frequency desired. The extent to which the Goertzel algorithm is more efficient than other algorithms (such as FFT) depends on the number of frequencies at which the DFT is to be computed.[4] The Goertzel algorithm is computationally less expensive as compared to FFT when

$$M < \log_2 N \tag{4}$$

Where M is DFT bins.
The filter has two pole system functions as follows [2].

$$H_K(K) = \frac{1-\omega_N^{-k} Z^{-1}}{1-2\cos(\frac{2\pi k}{N})Z^{-1}+Z^{-2}} \tag{5}$$

Figure 2 is the structure diagram, the two variance equations realized by the system is as follows:

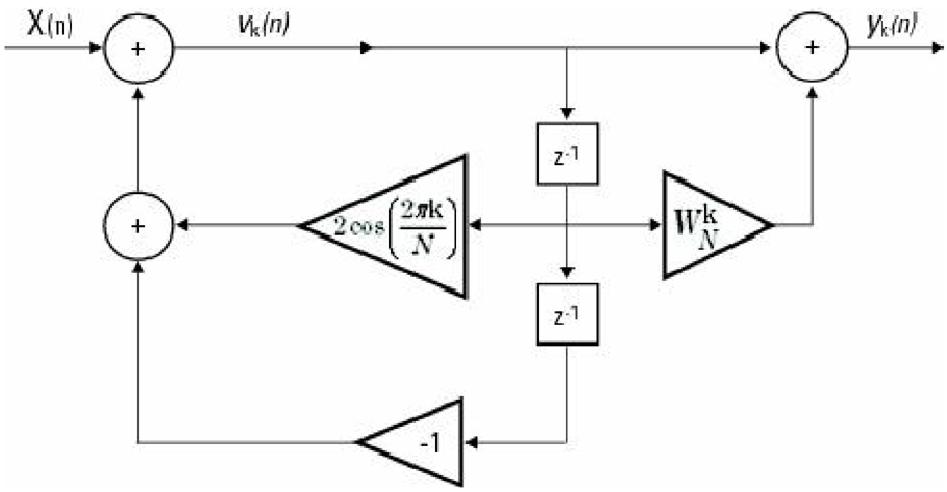

Figure 2: The Structure of Goerztal Algorithm.

$$v_k = x(n) + 2\cos\left(\frac{2\pi k}{N}\right) v_k(n-1) - v_k(n-2) \tag{6}$$

$$X(k) = y_k(N) = v_k(N)e^{-i\frac{2\pi}{N}nk} v_k(N-1) \tag{7}$$

Initial conditions: $v_k(1) = v_k(2) = 0$, that is the second real algorithm of Goertzel algorithm.The output at the point of n=N of the filter is the value at the frequency $\omega_k = 2\pi k/N$ of DFT, that is

$$X(k) = y_k(n)|_{n=N} \tag{8}$$

As the input signals are sequence of real numbers in the detection of DTMF, we need not to detect eight line frequency/column frequency phase, only the amplitude values or square amplitude values will be enough. So, the last step of the value of DTF of the calculation involved the molecular item (the forward parts of the Filters) can be simplified, therefore

$$|X(k)|^2 = y_k(N)^2 = |v_k(N) - v_k(N-1)|^2 \tag{9}$$

$$|X(k)|^2 = {v_k}^2(N) + v_k^2(N-1) - 2\cos\left(\frac{2\pi k}{N}\right) v_k(N-1) v_k(N) \tag{10}$$

The Correlative algorithm

Correlative method employs Euler's formula for the exponential function, resulting in a correlation of $u(t)$ with sine and cosine functions. As a result, the input frequency can be determined by correlating the input signal with the sine and cosine for each possible frequency. Correlation scheme is as follows. Let the input signal be $u(t) = A(sin\,(2\pi 697 \times t + \varphi_1) + sin\,(2\pi 1209 \times t + \varphi_2))$. Since the input signal includes $sin\,(2\pi 697t + \varphi_1)$, the correlation of the input signal with $sin\,(2\pi 697 \times t + \varphi_1)$ must be higher than the correlations with $sin\,(2\pi 770 \times t + \varphi_1), sin(2\pi 852\_t + \varphi_1)$, and $sin(2\pi 941 \times t + \varphi_1)$. The Fourier transform $\int u(t) e^{-ti\omega} dt$ has a peak at 697Hz. Using Euler's formula for the exponential function, it becomes a correlation of $u(t)$ with sine and cosine functions.

Comparison and Analysis

We have implemented the software generation and detection of DTMF in Matlab and the simulation results show that the Signal to Noise Ratio(SNR) as obtained is -10.88dB for FFT and Goertzel algorithm and -17.5 dB for correlative algorithm respectively. The tolerance value assumed in our case is 2%. The Goertzel algorithm uses half the number of real multiplications, the same number of real additions, and requires approximately $1/N$ the number of trigonometric evaluations as compared to a direct N-point DFT calculation. Thus the biggest advantage of the Goertzel algorithm over the direct DFT is the reduction of the trigonometric evaluations. The Goertzel method is more efficient than the FFT when a small number of spectrum points is required rather than the entire spectrum. However, for the entire spectrum, the Goertzel algorithm is an N^2 effort, just as is the direct DFT. Here in our case M = 2 and N = 1024 ,hence Goertzel algorithm will provide faster results as compared to FFT as values of M and N satisfy equation(4).We have also found that Correlative method provides a better noise performance as compared to the other methods but at the expense of a higher computation time. The FFT and goertzel algorithm are relatively faster but provide a poor noise immunity as compared to Correlation method.

Conclusion

This paper is based on the simulation of Dual-tone multi frequency signal and employs the comparison of the three detection algorithms based on their noise immunity and computational efficiency. Simulation is achieved by using Matlab, graphical user interface. Selection of algorithm is a Trade-off between noise immunity and computational efficiency and depends upon the application.

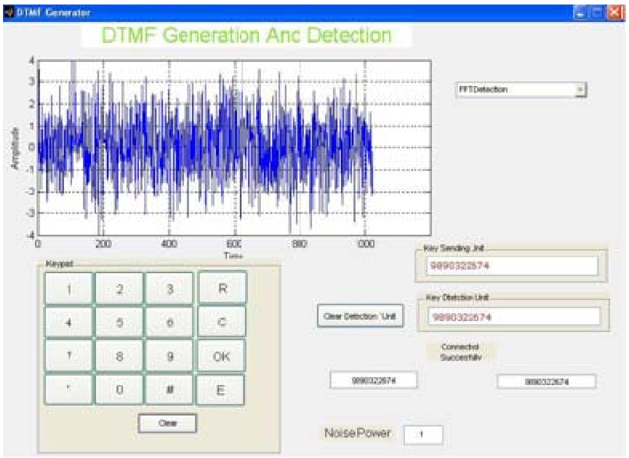

Figure 3: Detection using FFT.

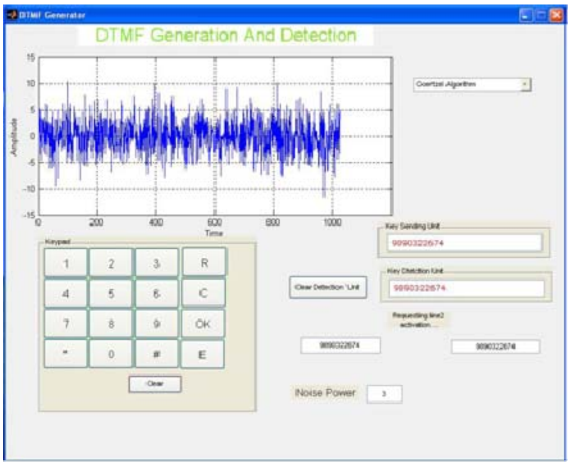

Figure 4: Detection using Goertzel Algoritm.

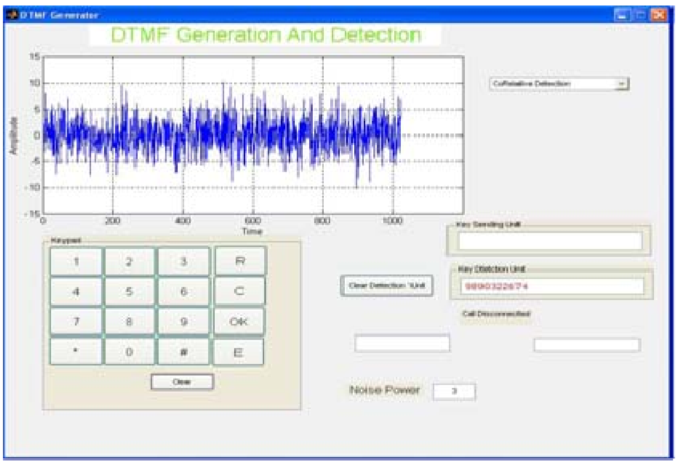

Figure 5: Detection using Correlative Scheme.

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