

Literature Survey
on

Dual-Tone Multiple Frequency (DTMF)
Detector Implementation

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Abstract

Dual-tone Multi-frequency (DTMF) Signals are used in touch-tone telephones as well as many other areas. Since analog devices are rapidly changing with digital devices, digital DTMF decoders become important. There are many DTMF decoding algorithms, but most of them cannot comply with the related International Telecommunications Union (ITU) and Bell Communications Research, Inc. (Bellcore) recommendations and/or are not suitable for real-time implementation. In this survey a brief review of some DTMF detector implementations is given. Although the Goertzel Algorithm is not able to satisfy the standards, it was the best approach in the sense of computational load and memory usage efficiency. It might be possible to use the Goertzel Algorithm with variable window length to satisfy the specifications.

The aim of this project is to implement a DTMF detector, which is ITU complaint, on a fixed point low cost DSP. This detector should be able to detect DTMF tones in multiple-channels with as much as possible channels.

1 Introduction

Dual-tone multi-frequency (DTMF) is an international signaling standard for telephone digits (number buttons). These signals are used in touch-tone telephone call signaling as well as many other areas such as interactive control applications, telephone banking and pager systems. Since analog devices are rapidly changing with digital devices, digital DTMF decoders become important. Digital implementation has many advantages over analog implementation such as better accuracy, stability, re-programmability and a lower chip count; that is, instead of using several analog chips for decoding multi-channel DTMF tones, using only a digital signal processor (DSP) chip for all channels.

Many digital DTMF decoding algorithms, have been proposed, but they have several drawbacks in general.

1. Most of them cannot comply with the related International Telecommunications Union (ITU) and Bell Communications Research, Inc. (Bellcore) recommendations.
2. Some of them have too heavy computational load
3. Some of them need too much memory to implement on a single fixed point DSP.

Although it does not satisfy the ITU specifications, the Goertzel Algorithm, which is an efficient algorithm to compute the Discrete Fourier Transform (DFT), is the most commonly used digital DTMF tone detection algorithm.

This survey is organized as follows. I will talk about the background of DTMF in section 2 and will review some commonly used DTMF detection algorithms in section 3. I will discuss the most commonly used, Goertzel Algorithm in section 4 and will conclude this survey and point out the future work in section 5.

2 Background

A DTMF signal consists of two superimposed sinusoidal waveforms whose frequencies are chosen from a set of eight standardized frequencies. For example, by pressing the “1” button from the touch-tone telephone key pad, a signal made by adding a 697 Hz and a 1209 Hz sinusoid is generated.

Detecting multi-frequency signals in noisy environments is a well studied area in DSP. The difficulty of DTMF tone detection is due to the standards which must be satisfied when

detecting these signals. Since these standards were determined when DTMF detectors were analog, applying the same standards to digital detectors might causes some problems. For example, the standard frequencies are determined in AT&T Bell Laboratories so that they have no common multipliers. This guarantees that none of the frequencies have common harmonics and thereby improves the performance of analog detectors. However, the most commonly used frequency analysis technique, the Discrete Fourier Transform (DFT), samples the frequency domain with equally spaced samples, and therefore, it is not possible to have a sample exactly at each standard frequency.

The ITU specifications are as follows:

1) Signal frequencies:

Low group (Hz): 697, 770, 852, 941

High group (Hz): 1209, 1336, 1477, 1633

2) ITU frequency tolerances:

a. Maximum accepted frequency offset is 1.5%

b. Minimum rejected frequency offset is 3.5%

3) Signal Reception Timing:

a. Minimum accepted tone duration is 23 ms,

b. Maximum rejected tone duration is 40 ms,

c. Minimum pause time between two tones is 40 ms,

d. Allowable interrupt within a tone is 10 ms,

4) Twist (power difference between frequencies):

a. The low frequency may have 8 dB higher power

b. The high frequency may have 4 dB higher power

Different from ITU, Bellcore has not only some recommendations but some standardized performance test as well. Some of these tests are performed using a digital simulation test tape which includes several speech samples containing energy at or near valid DTMF frequency-pairs. Bellcore Recommendations and test are as follows:

1) Bellcore frequency tolerances tests:

In this test, keeping one frequency constant other frequency is varied from -4% up to +4% with 0.1% steps. Bellcore requires that tones varying less then 1.5% detected and tones varying more that 3.5% rejected.

2) Bellcore guard time test:

Guard time is the minimal length of a tone that can be reliably detected. The guard time is determined by decreasing tone lengths at the input of the detector and counting the number of detects.

2) Bellcore twist test:

The twist is tested by applying DTMF tones with a twist decreasing 0.1 dB in every step.

3) Bellcore signal to noise ratio (SNR) test:

The detector should be work with a SNR at 23 dB or higher.

4) Bellcore power level test:

A minimum detection of 25 out of 35 at a tone power of -25 dBm is required, where $x\text{dBm}=10\log_{10}\left(\frac{x}{1\text{mW}}\right)$

5) Bellcore decode check:

This test consist of using all digits 10 times and counting the number of false detects.

6) Bellcore talk-off Tests:

One of the most important tests is the talk-off test which determines how often a detector detects a speech as a valid tone. Bellcore provides three one-hour audio tapes which includes over 50,000 speech samples to test a detector. Testing a DTMF detector with all these speech samples is equivalent to testing the detector on one million calls if it would used in a local central office.

3 DTMF Detection Algorithms

Since digital DTMF detectors have become so important, many techniques have been proposed and implemented. Some of them are summarized below.

Mock [1] implemented the Goertzel Algorithm on a TMS32010 signal processor. Since the Goertzel Algorithm is still the most commonly used DTMF decoding algorithm, I will discuss the details, including why it does not satisfy the ITU specifications, of the algorithm in section 4.

Gay *et al* [2] implemented two different algorithms on a *WE* DSP32. The first one was a Linear Prediction (LP) based algorithm which modeled each frequency with a two-pole autoregressive (AR) model. The signal from the channel is first down-sampled by a factor of 2

and then filtered by two band-pass filters which separated the two frequencies of the DTMF signal. Then, they computed the auto-correlation and cross-correlation of both sub-signals using an iterative algorithm and used these estimates in the normal equations to find the AR model coefficients. It is obvious to say that this algorithm will not meet the ITU specifications due to its high computational load. The second technique they implemented was the Goertzel Algorithm which will be discussed in the following section.

A relatively new work done by Bagchi *et al* [3] proposes a sub-band non-uniform Discrete Fourier Transform. The algorithm is based on the fact that the DTMF tone frequencies are low (The highest frequency is 1633 Hz.) compared to the sampling frequency (Sampling rate at telephone channels is 8 KHz). Thus after sub-band decomposition (Filtering the signal in a high-pass and low-pass section and applying a decimation by a factor of 2.) the low frequency part will include all the DTMF tones and the high frequency part can be omitted. This reduces the number of samples which will be used by the Goertzel Algorithm by a factor of two and, thereby, reduces the computational load. The disadvantages of this algorithm are that the sub-band decomposition itself needs some computation and delay, and the down-sampling procedure might cause some interference. Additionally since the signals high-pass section, which is generally used for talk-off test, is thrown away a, talk-off test cannot be applied.

In [4] we compared three different approaches to DTMF tone detection and implemented them on ADSP-2101 and Motorola 56001 signal processors. These three approaches include a subspace technique called **M**ultiple **S**ignal **C**lassification (MUSIC), an adaptive frequency estimation technique which was improved by a modification and named Normalized Direct Frequency Estimation Technique (NDFET) and the most popular Goertzel Algorithm. Our results were that the MUSIC algorithm has a very heavy computational load; that the NDFET is too sensitive to noise, and that, although the Goertzel Algorithm is not able to satisfy the standards, it was the best approach in the sense of computational load and memory usage efficiency.

DSP manufacturers Texas Instruments and Analog Devices published some application notes on DTMF detectors in [5] [6] [7]. All of these three applications used the Goertzel Algorithm.

The algorithm proposed by Felder *et al* [8], [9] is an efficient, digital, ITU complaint, zero buffering DTMF detection algorithm which can be implemented on a TMS320C5x digital signal processor to decode 24 channels using time-division-multiplexing (TDM).

4 Goertzel Algorithm

The Goertzel Algorithm uses the fact that the complex exponential in the Discrete Fourier Transform (DFT) equation is periodic and expresses the computation of DFT as a linear filtering operation defined by the difference equations,

$$s_k[n] = x[n] + 2\cos\left(\frac{2\pi k}{N}\right)s_k[n-1] - s_k[n-2] \quad (1)$$

$$y_k[n] = s_k[n] - e^{j\frac{2\pi k}{N}}s_k[n-1] \quad (2)$$

where the k th DFT coefficient is produced after the filter has processed N samples:

$$X[k] = y_k[n]|_{n=N} \quad (3)$$

Since in DTMF detection we are only considered in the power of the signal the square of the k th DFT coefficient can be computed instead of the complex DFT coefficient. In this case no complex multiplication or addition is needed which will decrease the computational complexity of the algorithm.

DFT is the method of sampling the frequency axes with equally spaced samples. If there is a frequency peak between two samples of the DFT, its amplitude will not be accurately obtained. This is due to the windowing effect. Since a limited number of samples are used to estimate the frequency, a smoothing will happen in the frequency domain. The windowing effect and the problem of the Goertzel Algorithm is shown in the figure bellow. In the figure, the dashed rectangular window indicates the frequencies which have to be accepted whereas the dot-dashed lines indicate the frequencies which have to be rejected according to the ITU specifications. The curve (absolute value of a sinc function) gives the amplitude which will be obtained from the Goertzel Algorithm (or DFT) when the related frequency is received. According to this figure, we have to accept values over 0.28, which is the minimum value inside the dashed window and reject the values below 0.38, which is the largest value outside the dot-dashed lines. This is a contradiction and source of the problem in using Goertzel Algorithm (or generally DFT).

The windowing effect has a very close relation with the number of samples N used in DFT. As mentioned before the standard DTMF frequencies are chosen such that they have no common multipliers. This is to prevent the interference of harmonics, but is a problem in determining N . The most often used value for N is 205, which minimizes an error defined as the difference between the actual standard frequencies and the nearest frequency sample of the DFT. But when this number is used the problem explain above will occur.

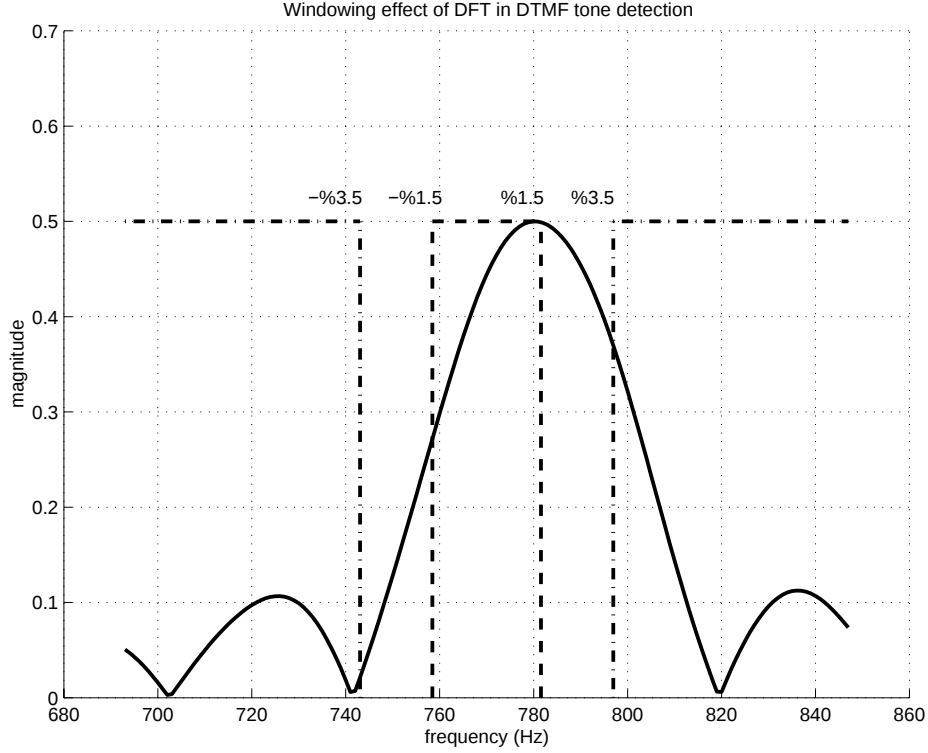


Figure 1: The amplitude of k^{th} ($k=20$) DFT coefficient for a window length of N ($N=205$)

A solution of this problem is to use different window lengths (N) for each frequency such that the dashed window in the figure is centered at our sinc window as much as possible.

5 Modeling and Implementation

I am going to test the variable window length Goertzel algorithm with the window numbers I have determined using simulations in MATLAB, for ITU and Bellcore compatibility.

Since for all of the DTMF algorithms mentioned the number of samples consumed and generated is known before the compilation time, the synchronous dataflow model can be used in modeling in Ptolemy. The decision logic, however, will be modeled with finite state machine.

Implementation will be as follows:

- 1) Modeling and simulating in Ptolemy,
- 2) Code generating for TMS320C5x in Ptolemy,
- 3) Optimizing the code by hand.

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