Spectral Analysis of Multichannel DTMF Signal Detection Algorithm with the QFT

Duck Gi Kim, Seung Gi Min, Jeng Sik Kim, Dal Hwan Yoon

Dept. of Electronics Engineering, Semyung University
E-mail : yoondh@venus.semyung.ac.kr

Abstract – The economical detection of dual-tone multifrequency(DTMF) signals is an important factor when developing cost-effective telecommunication equipment. Each channel has independently a DTMF receiver, and it informs the detected signal to processors. This paper analyze the power spectra and evaluate the performance of DTMF receiver by using the quick Fourier transform(QFT) algorithm. As experimental results, it show the improved performance to the DTMF receivers and reduce memory waste and process the real-time.

I. Introduction

The economical detection of DTMF(dual-tone multiple frequency) signals is critical importance in developing cost-effective telecommunications equipment. While many single-chip DTMF detectors currently exist, a multiple channel implementation is more appropriate in environments that have a concentration of many lines. In addition, a digital signal processor(DSP) implementation is often more desirable in applications such as switches where a single hardware resource may be shared among many channels and be used to perform many different signal processing functions at different times[1,2].

The DTMF receiver has independently each channel, and it informs the detected signal to the processor. The implementation of a DTMF receiver involves the detection of each of the signaling tones, validation of a correct tone pair, and timing to determine that a digit is present for the correct amount of time and with the correct spacing between tones. In addition, depending on the algorithm used to detect frequencies, it is sometimes necessary to perform additional tests to improve the performance of the decoder in the presence of speech. Current DSP technology allows several DTMF receivers to be implemented on a single device. A DSP implementation is useful in applications in which the digitized signal is available and several channels need to be processed, such as in a private branch exchange(PBX), or where other functions can be included on the same device.

In order to detect the signal, there are several methods using IIR filter, FIR filter and PARCOR method. Recently, the method to detect the signal use Goertzel algorithm and modified Goertzel(MG) algorithm. This method has an advantage that the calculation is easy and simply.

To analyze the power spectra and decide the detected signal, the QFT method proposed is compared with other algorithms. Especially, it shows highly efficient in both real-time and memory.

Ⅱ. The basic algorithm

The data received in DTMF receiver are transformed into the signal of the frequency domain by QFT. After that, it can happen the Gibbs phenomenon and the ripple. The Blackman window function and the zero-padding were used to reduce them.

The obtained impulse response s(n) is given by

$$s(n) = s_d(n)w(n), 0 \le n \le N-1 \quad (1)$$

Where $s_d(n)$ is real impulse response and w(n) represent window function. In equation (1), we use the symmetric properties of DFT to derive an efficient algorithm of s(n), and develop a basic QFT algorithm for arbitrary data lengths. Compared with Goertzel' method or other direct methods, the QFT will reduce the number of floating-point operations necessary compute the DFT by a factor of two or four. The algorithm has an interesting structure related to that of the DCT and DST, and it is well suited for the DFT's of real data.

The QFT algorithm can be easily modified to compute the DFT with only a subset either of input or output points. By using the respective even and odd symmetries of the cosine function and the sine function, the kernel of the DFT or the basis functions of the expansion is given by

$$S(k) = \sum_{n=0}^{N-1} s(n) e^{-j2\pi nk/N} \quad (2)$$

The equation (2) has an even real part and odd imaginary part. The complex data s(n) can be decomposed into its real and imaginary parts and those parts further decomposed into their even symmetric and odd symmetric parts. We have

$$\begin{aligned} s(n) &= u(n) + jv(n) \\ &= [u_e(n) + u_o(n)] + j[v_e(n) + v_o(n)] \quad (3) \end{aligned}$$

$$\begin{aligned} e^{-j2\pi nk/N} &= \cos(2\pi nk/N) \\ &\quad - j\sin(2\pi nk/N) \quad (4) \end{aligned}$$

In equation (3), the respective even and odd parts of the real part of x(n) are given by

$$u_e(n) = [u(n) + u(N-n)]/2 \quad (5)$$

$$u_o(n) = [u(n) - u(N-n)]/2 \quad (6)$$

Using a simpler notation with $\theta_{nk} = 2\pi nk/N$, the DFT of (2) becomes

$$S(k) = \sum_{n=0}^{N-1} [u(n) + jv(n)] [\cos\theta_{nk} - j\sin\theta_{nk}] \quad (7)$$

The sum over an integral number of periods of an odd function is zero, and the sum of an even function over half of the period is one half the sum over the whole period Then (7) becomes

$$\begin{aligned} S(k) = 2\sum_{n=0}^{N/2-1} \{ &[u_e(n)\cos\theta_{nk} + v_o(n)\sin\theta_{nk}] \\ &+ j[v_e(n)\cos\theta_{nk} - u_o(n)\sin\theta_{nk}]\} \quad (8) \end{aligned}$$

for $0 \le k \le N-1$. The evaluation of the DFT using (8) requires half as many real multiplications and half as many real additions as evaluating it using (2)-(7). This saving is independent of whether the length is composite or not. We should add the data points first then multiply the sum by the sine or cosine which requires one rather than two multiplications. Next, we take advantages of the symmetries of the sine and cosine as functions of the frequency index k, Using these symmetries on (8) gives

$$\begin{aligned} S(N-k) = 2\sum_{n=0}^{N/2-1} &\{[u_e(n)\cos\theta_{nk} + v_o(n)\sin\theta_{nk}] \\ &+ j[v_e(n)\cos\theta_{nk} - u_o(n)\sin\theta_{nk}]\} \quad (9) \end{aligned}$$

for $0 \le k \le N/2-1$.

Equations (8) reduce the number of operations by a factor of two because they calculate two output values at a time. The total algorithm, along with the mofied second-order Goertzel algorithm and the direct calculation of the QFT, requires N^2 real multiplications and N^2+4N real additions for complex data in Table 1.

Algorithm	real mults.	Real adds.	Trig. eval.
DFT	$4N^2$	$4N^2$	$2N^2$
Goertzel	N^2+N	$2N^2+N$	N
QFT	N^2	N^2+4N	$2N$

Table 1. Comparison of the number operations for O($N2$) DFT algorithms

Of the various algorithms of Table 1, the QFT seems to be the most efficient for an arbitrary length N. After processing the equation (8) by the QFT, a spectrum of frequency can be divided into low frequency and high frequency bands. It must be analyze the power spectrum of the split signal for each bands and decide the limits of the computed signal level. That is, we can define SNR as a total power and signal power P_S and signal power P_T which is a sum of the powers from each, $f_{\max}$ f_{next} whose power is $P_{\max}$,to $\pm i\Delta f$ (Δf : frequency sampling interval)

$$P_T = \sum_{k=-N}^{N} |S(k)|^2 , N > K \qquad (10)$$

$$P_{NS} \cong P_T - P_S , \qquad (11)$$

$$P_S \cong \sum_{i=-k}^{k} S(f_{\max} + i\Delta f) \qquad (12)$$

$$SNR = 20 \log_{10} (\tfrac{P_S}{P_{NS}}) \text{ [dB]} \qquad (13)$$

Where P_{NS} is the noise power. Eventually discriminating the kind and ID number of signal. By using equation(1)-(13) evaluate the performance of DTMF receiver. The experimental terms include the magnitude tests, the twist tests, frequency offset tests, and the tone-to-total energy tests, so on.

Ⅲ. Experimental results

Then an analyzed signal will be DTMF signal, it is displayed in monitor.

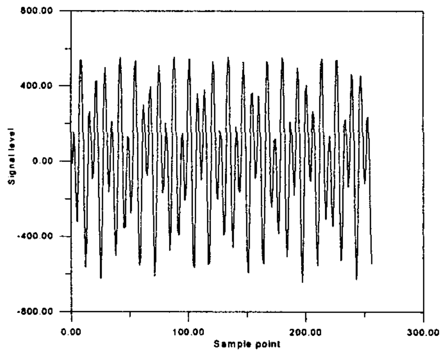
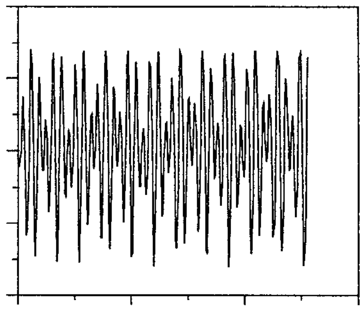
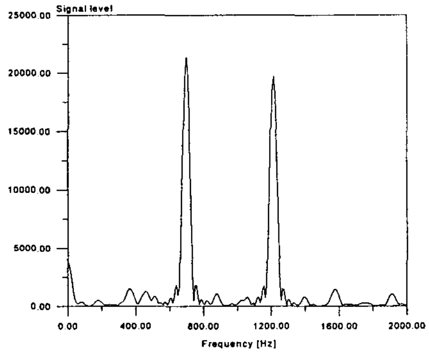


Figure 1 show signals waveform of the

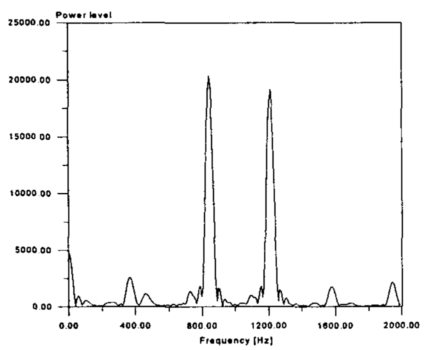


DTMF No.1

Figure 2 show signals waveform of the DTMF No.7



(a) Spectrum of DTMF No. 1



(a) Spectrum of DTMF No.7

IV. Conclusion.

In this paper, DTMF detection algorithm, highly efficient in both real-time and memory, were described. For the QFT based algorithm can be implemented on several DSP chip, and was found to have better digit simulation performance.

V. References

[1] Proutfoot A.D., "simple Multifrequency Tone Detector", Electron. Lett., Vol.8, pp 524-525, Oct.,1972

[2] Niwa K. and M. Sato, "Multifrequency Receiver for Push Button signaling Using Digital Processing Techniques", in Proc. Int. Conf. Commun., pp 18F1-5,1974.

[3] Koval A. and G. Gara, "Digital MF Receiver Using Discreate Fourier Transform", IEEE Trans. Commun., Vol. COM21 ,No.12, pp 1331-1335, Dec.1973.

[4] Alles H.G., J.H. Coden, W.C. Fisher and H.S. McDonald, "Digital Signal Processing in Telephone Switching", in Proc. Int. Conf. Commun., pp 18E.1-2, 1974

[5] Braun F.G., "Nonrecursive Digital Filters for Detecting Multifrequency Code Signalings", IEEE Trans. Acoust. Speech Signal Processing, Vol. ASSP-23, pp 250-256. June 1975.

[6] Callahan A.J., JR., "Integrated DTMF Receiver", IEEE Trans. Commun., Vol.COM-27, No.2, Feb.1979.

[7] Bodle K.J., N. Sachs and J. Tow, "Receiver for Touch – Tone Service", IEEE Trans. Commun. Electron., 1981.

[8] Tow J. and N. Sachs, " A DSP Implementation of Digital Tone Receiver ", IEEE Trans. Commun. Electron., 1981.

[9] Agarwal A.C., R. Sudhaker and B.P. Agrawal, "Multiplierless Implementation of MF/DTMF Receiver", IEEE Trans. Commun., Vol COM-32, NO.7 Jul 1984.

[10] Orfanidis, S.J., "Optimum Signal Processing", Macmillan, NewYork, 1985

[11] Oppenheim, A.V, and Schaeffer, R.W., "Digital Signal Processing", Prentice-Hall, Englewood Cliffs, NJ, 1975.

[12] Smith, G.L., "Dual-Tone Multifrequency Receiver Using the WE DSP16 Digital Signal Processto", Application Note, June 1989.

[13] Gay S.L., J. Hartung and G.L. Smith, "Algorithms for Multichannel DTMF Detection for the WE DSP32 Family", Proc. of ICASSP, Glascow Scotland, May 1989.