Digital Filter Array Optimization for Directivity Pattern

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Abstract—Two microphone arrays are used for producing a specific directivity pattern by a time delay between the two microphones. Directional hearing aids are examples of the two microphone arrays application. In this paper, the conventional time delay method was replaced with a digital filter method for directional digital hearing aids. CSR8675 multimedia digital signal processing hybrid was used for the main platform of the suggested digital filter method instead of well-known specific digital hearing aid DSP hybrids. The results of the suggested filter method were well matched with those of the time delay method.

Keywords-CSR8675; Digital Signal Processing; Digital Filter; Optimization; Directional Hearing Aids; Phase Difference

I. INTRODUCTION

One of hearing aid main functions is directivity. This implies that voices from some specific direction sound louder than other voices from other directions. The directionality can be realized by arrays of omnidirectional microphones. For example, if two microphones of the same sensitivity are located in the direction of one axis, the directivity can be produced by delaying and subtracting of signals between the two microphone outputs [1]. This conventional time delay method requires a precise time delay and signal subtraction control units. When the distance between two microphones is changed, the delay time should also be changed. The scale of the delay time is some microseconds in unit. Well-known DSP hybrids such as Ezairo5920 or Ezairo7110 are equipped with this time delay module for digital hearing aid application purpose, but they are expensive [2].

CSR8675 Bluetooth (BT) hybrid studied in this paper is cheap and has many Bluetooth features, but it doesn’t have the time delay module between two microphones in stereo channels (right channel and left channel) [3]. In the paper the conventional time delay method was replaced with digital filters for realizing the directivity of CSR8675 hybrid IC chip.

II. PHASE DIFFERENCE BY DIGITAL FILTERS

Figure 1 shows the time delay method in the diagram. One front microphone is separated from the other rear microphone with D distance. Both microphones are located in the same directional axis. The output of the rear microphone signal is delayed with T and is subtracted from the output of the front microphone, and the result, x(t), is converted to a digital signal, x[n]. n = integer discrete number.

Figure 2 shows the digital filter method. Both front and rear microphone outputs are converted to digital signals, x₁[n] and x₂[n], and they are passed through digital filters, DF1 and DF2, resulting y₁[n] and y₂[n]. Then y₁[n] is subtracted from y₂[n], y[n]= y₁[n] - y₂[n].
Figure 3 shows the 2nd order IIR (Infinite Impulse Response) digital filter layout. There are 5 coefficients; $a_1$, $a_2$, $b_0$, $b_1$, $b_2$. $y[n]$ is computed from $x[n]$ as follows:

$$y[n] = -a_1y[n-1] - a_2y[n-2] + b_0x[n] + b_1x[n-1] + b_2x[n-2]$$  

Figure 3. 2nd order IIR digital filter layout.

Digital signal filtered by either DF1 or DF2 changes in its magnitude and phase response as a function of frequency depending on the values of the filter coefficients. If DF1 and DF2 are optimally designed so as to produce the same magnitude response, but the constant phase difference response between DF1 and DF2, the resulting $y[n]$ in figure 2 should be the same as $x[n]$ in figure 1.

There are 10 digital filter coefficients for the two digital filters: $a_1^1$, $a_2^1$, $b_0^1$, $b_1^1$, $b_2^1$ and $a_1^2$, $a_2^2$, $b_0^2$, $b_1^2$, $b_2^2$. We applied Nelder-Mead optimization method in order to compute the optimal filter coefficients producing the same time delay or phase difference effects [4-6].

III. PHASE DIFFERENCE BY DIGITAL FILTERS

The sound transmission speed is set up as 343 m/sec at 20°C. And $D = 9$mm, the sampling frequency is 16kHz. Cardioid directivity pattern was considered, so that $T$ should be 26.239μs [7]. The filter coefficients are optimized to have a unit magnitude and $2\pi T$ phase difference along the frequency.

Figure 4 shows the cardioid directivity patterns of the time delay method. Three frequencies, 500Hz(continuous), 2kHz(dotted), 4kHz(dashed), were considered. The maximum sensitivity is figured as 40[dB] while the center is 0[dB]. $0°$ indicates the front direction while $180°$ is in the rear.

And figure 5 shows the cardioid directivity pattern of the digital filter method. $a_1^1$, $a_2^1$, $b_0^1$, $b_1^1$, $b_2^1$ and $a_1^2$, $a_2^2$, $b_0^2$, $b_1^2$, $b_2^2$ are optimally computed as follows:

$$a_0^1 = 1.0, \quad a_1^1 = 1.2962, \quad a_2^1 = 0.3496,$$
$$b_0^1 = -0.3496, \quad b_1^1 = -1.2962, \quad b_2^1 = -1.0$$

$$a_0^2 = 1.0, \quad a_1^2 = 0.8770, \quad a_2^2 = 0.1012,$$
$$b_0^2 = -0.1012, \quad b_1^2 = -0.8770, \quad b_2^2 = -1.0$$

Figure 4 and figure 5 show almost the same cardioid directivity patterns with different methods. The digital filters are noticed as symmetric, that is, $a_0^1 = b_2^1$, $a_1^1 = b_1^1$, $a_2^1 = b_0^1$. Therefore the filter coefficients’ optimization can be done with only 4 parameters instead of 10.

Figure 4. Directivity of time delay method, $\beta=1$(cardioid).

Figure 5. Directivity of digital filter method, $\beta=1$(cardioid).
Figure 6 shows the frequency response of the maximum sensitivity magnitude for the same cardioid directivity patterns. The time delay result is drawn by continuous lines while the digital filter method is done by rounds. Both results are very close.

Figure 7 shows the directivity patterns of the filter method with three microphone arrays. The distance between two adjacent microphones is 11mm. The beamform of the three microphone arrays looks narrower than that of the two microphone arrays. But the maximum sensitivity decreases more rapidly for lower frequency (6dB/oct. to 12dB/oct. in Figure 8).

IV. CONCLUSIONS

This paper compared directivity patterns of conventional time delay method with suggested digital filter method. Both results showed almost the same results for a specific time delay value of cardioid pattern. The 2nd order two digital filters are optimized to produce the same phase difference as the delay time. The optimally computed coefficients indicated that only 4 coefficients are good enough instead of 10 parameters. We’ll continue research for other directivity patterns and find how the filter coefficients are correlated. This work would be further useful for scanning directional beam pattern not only for 2D but also for 3D in medical imaging technology..

ACKNOWLEDGMENT

This study was supported by research fund from the ministry of commerce, industry and energy (MOCIE Korea) 2015 core medical device commercialization technology development project (smartphone controlled 64 channel digital hearing aid with 6dB voice SNR (Signal to Noise Ratio) improvement: project number 10054678) in 2015.

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