RESEARCH ON CUSTOMIZED VIRTUAL BASS ALGORITHMS FOR DIFFERENT KINDS OF MICROLOUDSPEAKERS

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In recent years, micro loudspeakers have gained immense popularity with mobile multimedia system. Unfortunately, due to size constrains, their designs have poor performance at low frequency. Virtual bass algorithm based on "virtual pitch" theory is a popular solution to improve the low frequency sound quality. However, these virtual bass algorithms do not take into account the characteristics of the loudspeaker, which would lead to significant difference of subjective perception. In this paper, two kinds of typical television loudspeakers are selected to evaluate the customized processing of the virtual bass algorithm by selecting the cut-off frequency of low-pass filter. The subjective experimental results show that the perceptual performance of each kind of television loudspeakers is the best when the cut-off frequency of low-pass filter matches the cut-off frequency of the loudspeaker.

Keywords: virtual bass, television loudspeaker, customized processing

1. Introduction

With the rapid evolution of technology advancements and the consumers’ demand in better visual enjoyment, the flat-panel televisions have become more popular. An associated implication of these requirements is the size reduction of loudspeakers used in televisions. Small loudspeakers usually have high cut-off frequencies and poor low-frequency performance. The contradiction between consumers’ pursuit of high-quality music and poor low-frequency performance of small loudspeakers has become an urgent problem to be solved.

Traditional method in addressing the problem of poor low-frequency performance is to simply boost up the weak signals at low frequency bands. However, this method leads to an increase of power consumption, distortion, and nonlinear response of loudspeakers. To peruse a perceptual low frequency subjective effect, without pushing the physical limit of loudspeakers, a psychoacoustic phenomenon, called the “Missing Fundamental” is the common method. The “Missing Fundamental” phenomenon states that human can perceive the virtual pitch at the fundamental frequency when the harmonics are present, even if the fundamental frequency itself is removed or not present [1].

This topic has been well-researched by various researchers. The methods of virtual pitch can generally be divided into two categories: time-domain method and frequency-domain method. The NLD (Nonlinear Devices) algorithm operates in the time domain and is the most common method. Many researchers have conducted in-depth studies on the NLD algorithm, such as Oo [2], Arora [3] and so on. The PV (Phase Vocoder) algorithm operates in the frequency domain and was first proposed by Bai [4] et al. in 2006. What’s more, an idea of the hybrid virtual bass system, which combines NLD and PV, was studied and explored by Hill [5, 6], Mu [7], Hoffmann [8] and so on. In this paper, the time-domain approach called NLD which has low computational complexity is used.
to generate the required harmonics based on the incoming audio signal. However, a pre-designed NLD algorithm would not achieve the maximum bass effects from one kind of loudspeakers to another kind of loudspeakers without taking into account the characteristics of the loudspeakers. This paper will customize the virtual bass NLD algorithm for different kinds of television loudspeakers by selecting the cut-off frequency of low-pass filter in the algorithm. Subjective results are presented with a discussion on the bass effect of the customized algorithm.

2. Theory

2.1 Traditional NLD algorithm

The traditional NLD (Nonlinear Devices) algorithm [9, 10] is a time domain method, which generates harmonics based on nonlinear devices. A polynomial-based NLD [11] can be described as

\[ y = h_1 x + h_2 x^2 + L + h_n x^n. \]  

(1)

where \( h_1, h_2, \ldots, h_n \) are coefficients of the polynomials and \( n \) is the highest order of the polynomials. \( x \) and \( y \) denote the input and output signals, respectively. The polynomial-based NLD is a memoryless nonlinear system. The current output sample only depends on the current input sample. This system can be depicted as shown in Fig. 1.

The generated harmonics (a single tone) including DC term and the fundamental frequency can be described as

\[ y = 0.5c_0 + c_1 \cos \omega_b + c_2 \cos 2\omega_b + L + c_n \cos n\omega_b. \]  

(2)

where \( c_0 \) is a DC term, and \( c_1, \ldots, c_n \) are the magnitudes of the harmonics.

R. A. Schaefer derived the generalized polynomial analysis and synthesis equations using Chebyshev polynomials of the first kind [12]. Schaefer’s harmonics synthesis equation is given as

\[ h_p = \frac{2^{p-1}}{p!} \sum_{i=0}^{\infty} (-1)^i c_{p+2i} (p + 2i) \left[ \frac{(p + i - 1)!}{i!} \right]. \]  

(3)
The schematic of the traditional NLD virtual-bass algorithm is shown in Fig. 2. The input signal is filtered by a low-pass filter (LPF) with a certain cut-off frequency, and then followed by the NLD, which is used to generate the harmonic components. Next, the NLD output is fed to a bandpass filter (BPF) to remove the fundamental spectral components and to roughly shape the harmonic components. The lower limit frequency of the bandpass filter is equal to the cut-off frequency of the low-pass filter. After the BPF, an adjustment gain is multiplied by the signal and then the gained signal is combined with a delayed version of the original signal.

2.2 Customized algorithm

Due to the different characteristics of micro loudspeakers, a pre-designed NLD algorithm would not achieve the maximum bass effects from one kind of loudspeakers to another kind of loudspeakers. For a specific loudspeaker with a fixed cut-off frequency, the effect of bass boost varies with the change of the cut-off frequency of low-pass filter in the NLD algorithm. The cut-off frequency of low-pass filter in the NLD algorithm will be adapted to find out the best effect of bass boost for a specific loudspeaker.

3. Subjective evaluation and results

Subjective testings were carried out in the Audio Research Laboratory listening room at Nanjing University. Two different kinds of television speakers were used in the test. As shown in Fig. 3, one was from Sharp whose cut-off frequency is approximately 250 Hz and the other was from Hisense whose cut-off frequency is approximately 150 Hz. The power amplifier used in the test was Anty PA3002. As shown in Fig. 4, the loudspeakers and the power amplifier were placed on a table in the middle of the listening room. The distance between the listener and the loudspeaker is about 2.5 meters, it would be a suitable distance when watching TV.
A total of 15 experienced listeners (thirteen males and two females, 22-25 years old) were recruited for the listening test. All listeners have good listening ability and could therefore be considered to be reliable listeners.

*Red Flowers Blooming All Over the Mountain* was chosen as the tested audio file because it had enough amount of bass energies. Four audio files were obtained using the NLD algorithm with the cut-off frequency of low-pass filter of 150 Hz, 250 Hz, 450 Hz and 700 Hz respectively. Appropriate values for the harmonics’ magnitudes were selected.

The listeners were presented with three groups of audio files and were asked to choose the best one in bass effect in each group. The first group of audio files including four processed musical samples with the cut-off frequency of low-pass filter in the algorithm of 150 Hz, 250 Hz, 450 Hz and 700 Hz respectively was played by the television speakers of Hisense. The second group including three processed musical samples with the cut-off frequency of low-pass filter in the algorithm of 250 Hz, 450 Hz and 700 Hz respectively was played by the television speakers of Sharp. The third group including two processed musical samples with the cut-off frequency of low-pass filter in the algorithm of 150 Hz and 250 Hz respectively was played by the television speakers of Sharp. The order of each group of audio files was messed up randomly. Each listener completed the test during independent sessions.

Table 1: The best bass effect voted by listeners (the first group played by Hisense)

<table>
<thead>
<tr>
<th>Cut-off frequency of low-pass filter</th>
<th>150 Hz</th>
<th>250 Hz</th>
<th>450 Hz</th>
<th>700 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of listeners</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: The best bass effect voted by listeners (the second group played by Sharp)

<table>
<thead>
<tr>
<th>Cut-off frequency of low-pass filter</th>
<th>250 Hz</th>
<th>450 Hz</th>
<th>700 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of listeners</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3: The better bass effect voted by listeners (the third group played by Sharp)

<table>
<thead>
<tr>
<th>Cut-off frequency of low-pass filter</th>
<th>150 Hz</th>
<th>250 Hz</th>
<th>The same</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of listeners</td>
<td>7</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

The subjective evaluation results are presented in table 1-3. Table 1 shows that all the fifteen listeners chose the processed musical sample with the cut-off frequency of low-pass filter in the algorithm of 150 Hz among the four audio files in the first group played by the television speakers of Hisense for the best one in bass perception. Table 2 shows that all the fifteen listeners chose the processed musical sample with the cut-off frequency of low-pass filter in the algorithm of 250 Hz among the three audio files in the second group played by the television speakers of Sharp for the best one in bass perception. Table 3 shows that between the processed musical samples with the cut-off frequency of low-pass filter in the algorithm of 150 Hz and 250 Hz in the third group played by the television speakers of Sharp, seven listeners chose the former for the better one in bass perception while six listeners chose the latter for the better one in bass perception. What’s more, the other two listeners held the view that the two processed musical samples were about the same and they could not tell which was better.
The subjective evaluation results indicate that for the television speakers of Hisense, the processed musical sample with the cut-off frequency of low-pass filter in the algorithm of 150 Hz has the best effects of bass enhancement. For the television speakers of Sharp the processed musical samples with the cut-off frequency of low-pass filter in the algorithm of 150 Hz and 250 Hz are the top two in bass perception. What’s more, the bass effects of the two samples are about the same. However, the energy of the generated harmonic components of the processed musical sample with the cut-off frequency of low-pass filter in the algorithm of 150 Hz focuses on the frequency bands of 150 Hz to 300 Hz while the cut-off frequency of the television speakers of Sharp is 250 Hz. Because most of the energy is under the cut-off frequency of loudspeakers, it is equal to simply boosting up the weak signals at low frequency band as the traditional method mentioned in Section 1. However, the traditional method will lead to distortion and the nonlinear response of the loudspeaker. As a result, the processed musical sample with the cut-off frequency of low-pass filter in the algorithm of 250 Hz is a better choice for the television speakers of Sharp.

The subjective evaluations have shown that the perceptual performance of bass effects of each kind of loudspeakers is best when the cut-off frequency of low-pass filter matches the cut-off frequency of the loudspeaker.

4. Conclusion

Based on the NLD algorithm, virtual bass algorithms were processed in a customized way by selecting the cut-off frequency of low-pass filter according to the characteristics of the loudspeaker. Subjective evaluation was carried out to vote for the best effects of bass enhancement and it was found that the loudspeaker had the best perceptual performance of bass effects when the cut-off frequency of low-pass filter in the algorithm matched the cut-off frequency of the loudspeaker.

REFERENCES
