Implementation of CIS speech signal processing for cochlear implants by using Bark scale frequency band partition

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Abstract A new method on the basis of Bark scale frequency-band partition was presented to improve the recognition performance of cochlear implants. In the nature of physics, it consists with human’s cochlea filter properties. The mechanism of a cochlear implant and its CIS speech processing strategy were presented. Also the time-frequency analyzing property of human's cochlea was analyzed.

The theoretical determination of Bark scale frequency-band was also given with formula. Simulation results using Bark scale transform signal processing were discussed in detail and results show that the new method is feasible in speech processors for cochlear implants.

Key words cochlear implant, Bark scale, CIS strategy, speech signal processing

1 Introduction

Cochlear Implant is a hearing device restoring hearing ability to the deaf with electricity stimulation. It mainly acts as imitating the physiological function of peripheral acoustical nerve such as outer, middle and inner ear of normal people. The nucleus of surrounding acoustical system is cochlea in inner ear. Cochlea is a snail-shaped organ that translates sound energy into nerve impulses and then sends them to the brain for processing. Sound is transmitted in the form of traveling wave, so cochlea can be taken as theoretically that it is composed of a group of space-distributed band-filters, and the same long basilar membrane (about 1.5mm) in cochlea is equivalent to a filter of same bandwidth called Bark scale domain [1,2]. Multi-channel cochlear implant is designed based on cochlea’s filtering properties for speech signal. Speech signal-processor deals with speech signal in segment band, and produces simulating signal of corresponding electrodes to excite different part acoustical nerve in cochlear.

CIS strategy is one of signal processing algorithms that a cochlear implant presently adopts. It divides speech signal into sub-bands using band filters from 4 to 8, and then detects out envelope information of each band signal to produce electrical stimulation current. In CIS signal processing algorithm, the bandwidth of filters usually is logarithm-law or octave-law relation. However, this frequency-band partition of filters is not completely consistent with the nature of physics which is inherent in human ear. So the speech recognition performance of CIS strategy should be improved.

According to above analysis, this paper discusses the application of Bark scale transform in speech signal-processing of cochlear implants. We hope that the results would provide reference to the implementation of speech signal digital processing in cochlear implants, and at the same time, the relevant conclusion would be helpful for improving the speech recognizing ability of the deaf.

2 CIS speech signal processing strategy for cochlear implants

2.1 The mechanism of cochleae implants

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When sound signal transmits in the form of traveling wave in cochlea, the amplitude of its high frequency band is the strongest in cochlea’s basal end, and the amplitude of its low frequency-band is the strongest in cochlea’s apical end. So the cochlea is a mechanical-frequency analyzer in the space.

The basal end of cochlea accepts high-frequency signal and the apical end accepts low-frequency signal. Acoustical frequency between the apical end and the basal end along the basilar membrane ranges from 16Hz to 20kHz. Physiological experiments give further evidence that the frequency-analyzing feature of cochlea is similar to that of the same bandwidth filters in Bark scale domain. The frequency bandwidth of each filter is approximately equal to the length of basilar membrane in cochlea which includes about 1200 pieces of nerve fiber.

Cochlear implant is the imitation of normal hearing man’s cochlea. In artificial cochlea, a group of electrodes is implanted into cochlea’s scala tympani along the basilar membrane. The speech processor outside of body produces electricity-stimulating signals corresponding to electrodes. The implanted circuit of generating stimulating-electricity current inner body produces stimulating-pulses. These pulses activate intact auditory nerves in cochlea. Then the exciting of auditory nerves near all electrodes is transmitted to speech center of pallium to induce hearing perceptual ability, and so restore primary language communication ability for the deaf.

2.2 CIS speech signal processing strategy in cochlear implants

The schematics of CIS speech signal processing strategy in cochlea implant is showed in figure 1. In CIS strategy, the speech signal is firstly pre-amplified and then divided into 4 to 8 sub-band with a group of frequency-band filters. Thus after every sub-band signal is rectified and envelope-demodulated, we would gain every sub-band envelope signal. Finally envelope signal will be compressed to appropriate dynamic range with logarithm-law or square-law. The stimulating pulses for all electrodes can be gained by modulating envelope signal with interleaved bipolar pulse-sequences [3~5].

Electrical stimulation pulsatile current in CIS speech signal-processing strategy would be gained according to the varied amplitude of sub-band signal, also called envelope signal. The number of electrodes usually is less than 10 (maybe from 4 to 8 channels) [6], so how frequency-band partition should be made is critical for gaining effective parameters of stimulating electrodes, consequently the optimal recognition performance can be obtained. The frequency-bandwidth of filters in figure 1 is usually octave-law relation (i.e. if the frequency-band of BPF1 is from 0Hz to f0, the band of BPF2 would be from f0 to nf0, and that of BPF3 would be from n*f0 to n*n*f0 and so on, where n is integer) or logarithm-law relation. These band filters can be implemented in the form of digital or analog filter. At present, the implementation of filtering in cochlea implant is based on digital filter[7,8]. The band-pass filters with frequency-band partition of speech signal in Bark scale domain consist with human’s cochlea filter properties. The stimulating pulses which are derived from envelopes can effectively represent ones produced by nerve fibers on the same long basilar membrane of cochlea. This paper develops a new speech signal-processing method in cochlea implant where frequency-band partition of band-pass filters is based on Bark scale transform.

3 Bark Scale transform and its implementation in CIS strategy

3.1 definition of Bark Scale transform

The function of basilar membrane is similar to frequency-spectra analyzer. We can separate...
frequency of speech signal ranging from 20 to 16,000Hz into 24 frequency groups (critical band), and this partition of frequency groups is consistent with division of basilar membrane into many same long small parts. Each small part of basilar membrane is corresponding to a frequency group. The sound of these frequencies on the same segment of basilar membrane may be evaluated as a whole by adding them together. So we can say that the corresponding relation between perceptual frequency of auditory organ and actual frequency of sound signal is nonlinearly mapped. So the concept of Bark scale can be introduced. Traumullar presented the function relation between linear frequency and Bark scale frequency, i.e.:

\[ b = 6.7 \text{asinh} \left( \frac{(f - 20)}{600} \right) \]

or

\[ b = \frac{26.81 f}{(1960 + f)} \]

Where \( b \) denotes Bark scale frequency, \( f \) is linear frequency. Their relation is showed in figure 2.

3.2 the implementation of CIS strategy with Bark scale transform in cochlea implant

In the nature of physics, the frequency-band partition in Bark scale domain consists with human’s cochlea filter properties. So the band division of Bark scale domain can replace the partition of logarithm-law or octave-law in band-pass filters of CIS speech signal-processing algorithm. In experiment, firstly speech signal is divided into sub-band wave using band-pass filters with Bark scale transform. Secondly every sub-band signal is all-wave rectified and low-pass filtered to produce envelope signal. The cosine wave whose frequency is the center frequency corresponding to band-pass filter modulates envelope signal. Finally modulated signal after added directly together drives loudhailer to sound. The schematics of CIS strategy is showed in figure 3. In this experiment, the performance of synthesized speech signal is estimated by normal people, so this algorithm takes no account of amplitude dynamic-range and omits compressing function.

In CIS speech signal-processing strategy, the number of electrodes is less than 10 (usually from 4 to 8). However Bark scale domain can be divided into 24 frequency-groups(clinical band) between 20 and 16,000Hz, so it’s necessary that a few clinical bands should be combined together as bandwidth of band-pass filter according to sampling frequency of speech signal.

In this paper, we carried out an experiment on different number channels of CIS strategies with Bark scale transform, and the center frequency of corresponding band-pass filters. Table 1 and 2 respectively show center frequency, serial number of Bark scale and frequency-band in 6 and 8-channels CIS strategy. The sampling frequency of speech signal is 11,025Hz.

4 results and discussion

In our experiment, the input speech signal of “Time, Good” (Fs=11.025kHz, 8bit) is analyzed and processed with CIS strategy using Bark scale transform, and then cosine signal whose frequency is the center frequency of corresponding band-pass filters modulates processed signal. Finally modulated signal is added to form synthesized speech signal.
TABLE 2 The center frequency of 6-channel band filter and serial numbers of Bark scale domain

<table>
<thead>
<tr>
<th>Center frequency (Hz)</th>
<th>Frequency range (Hz)</th>
<th>Serial number of Bark domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>265</td>
<td>20&lt;~510</td>
<td>1~5</td>
</tr>
<tr>
<td>640</td>
<td>510&lt;~770</td>
<td>6~7</td>
</tr>
<tr>
<td>1020</td>
<td>770&lt;~1270</td>
<td>8~10</td>
</tr>
<tr>
<td>1635</td>
<td>1270&lt;~2000</td>
<td>11~13</td>
</tr>
<tr>
<td>2575</td>
<td>2000&lt;~3150</td>
<td>14~16</td>
</tr>
<tr>
<td>4335</td>
<td>3150&lt;~5500</td>
<td>17~19</td>
</tr>
</tbody>
</table>

TABLE 2 The center frequency of 8-channel band filter and the serial numbers of Bark scale domain

<table>
<thead>
<tr>
<th>Center frequency (Hz)</th>
<th>Frequency range (Hz)</th>
<th>Serial number of Bark domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>20&lt;~400</td>
<td>1~4</td>
</tr>
<tr>
<td>515</td>
<td>400&lt;~630</td>
<td>5~6</td>
</tr>
<tr>
<td>775</td>
<td>630&lt;~920</td>
<td>7~8</td>
</tr>
<tr>
<td>1095</td>
<td>920&lt;~1270</td>
<td>9~10</td>
</tr>
<tr>
<td>1495</td>
<td>1270&lt;~1720</td>
<td>11~12</td>
</tr>
<tr>
<td>2210</td>
<td>1720&lt;~2700</td>
<td>13~15</td>
</tr>
<tr>
<td>3200</td>
<td>2700&lt;~3700</td>
<td>16~17</td>
</tr>
<tr>
<td>4610</td>
<td>3700&lt;~5500</td>
<td>18~19</td>
</tr>
</tbody>
</table>

The frequency-cut of low-pass filter which extracts envelope signal is 400Hz. Band-pass filters and low-pass demodulating filter are designed in the form of elliptical properties under Matlab environment. Band-passed signal is all-wave rectified, i.e.: the negative amplitude value is reversed and the positive is not changed.

In experiment, the original speech signal of “Time and Good” was processed with different number channels (from 4 to 8) presented CIS strategy and the experimental results were obtained. In this paper, we only displays simulating results of 8 channels CIS strategy. Figure 4 (a) shows original wave of “Time and Good”; (b) shows synthesized speech wave after processed with CIS strategy. Figure 5 shows rectified envelope signal of “Time” filtered with 8 band-pass elliptical filters. The center frequency and bandwidth of all band-pass filters are showed in table 2.

We see from figure 4 that the synthesized speech signal using CIS strategy with Bark scale transform basically is consistent with original signal. Normal people can identify the sound which loudhailer utter with synthesized signal. In this signal-processing strategy, the combination of Bark scale serial numbers forms bandwidth of band-pass filters, such as bandwidth. Envelope information of different band is obtain by filtering speech signal, and synthesized signal basically represents original speech. At the same time, this paper present a new method of frequency-band partition for CIS speech signal-processing strategy, and the speech signal-processing in cochlea implant consists with the physiological nature of cochlea.

5 conclusion

This paper discusses the method of frequency-band partition in Bark scale domain adopted in speech signal-processing strategy of cochlea implant, and presents a new design scheme for cochlea implant.
The experimental result shows that the frequency-band partition replacement of octave-law or logarithm-law in CIS strategy with Bark scale domain is feasible. The different combination of a few Bark serial numbers would forms CIS speech signal-processing of different channel number (from 4 to 8), and this frequency-band partition consists with human’s cochlea filter properties. In this paper, we processed speech signal with CIS strategy under Matlab. The compressing function for adjusting envelope amplitude is taken out. Envelope signal is directly modulated and then drives loudhailer to sound after added together. Results show that the sound which synthesized signal drive loudhailer to emit can be identified in principle by normal people.

Reference