Tonal Language Speech Compression Based on a Bitrate Scalable
Multi-Pulse Based Code Excited Linear Prediction Coder

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Abstract: Problem statement: Speech compression is an important issue in the modern digital speech communication. The functionality of bitrates scalability also plays significant role, since the capacity of communication system varies all the time. When considering tonal speech, such as Thai, tone plays important role on the naturalness and the intelligibility of the speech, it must be treated appropriately. Therefore these issues are taken into account in this study. Approach: This study proposes a modification of flexible Multi-Pulse based Code Excited Linear Predictive (MP-CELP) coder with bitrates scalabilities for tonal language speech in the multimedia applications. The coder consists of a core coder and bitrates scalable tools. The high pitch delay resolutions are applied to the adaptive codebook of core coder for tonal language speech quality improvement. The bitrates scalable tool employs multi-stage excitation coding based on an embedded-coding approach. The multi-pulse excitation codebook at each stage is adaptively produced depending on the selected excitation signal at the previous stage. Results: The experimental results show that the speech quality of the proposed coder is improved above the speech quality of the conventional coder without pitch-resolution adaptation. Conclusion: From the study, the proposed approach is able to improve the speech compression quality for tonal language and the functionality of bitrates scalability is also developed.

Key words: Thai speech, Multi-Pulse based Code Excited Linear Predictive (MP-CELP), speech compression, bitrates scalability, Conjugate-Structure Algebraic Code Excited Linear Predictive (CS-ACELP), Tone (T), bitrates scalable, High Pitch Delay Resolutions (HPDR), MOS scores

INTRODUCTION

In the present days, the digital communications are widely developed (Jabrane et al., 2007). The audio, images, video or data information can be transmitted through wire or wireless network channels. Simultaneously, the number of users to access these networks increases rapidly. Consequently, channel capacity has to be increased, signal compression aims to perform this (Chompun et al., 2000). Since the multimedia applications such as videophone and videoconference on ATM and Internet are widely used, the high quality speech codes are highly demanded. These kinds of applications require special considerations for packet loss. To overcome this problem, it is to realize a scalable coder where the synthesized speech signal can be decoded from the received packets, which contain only a part of the whole encoded bitstream. One of standardization activities for such areas is undergoing at the MPEG-4 (Nomura et al., 1998; Chomphan, 2010b).

In 1995, Conjugate-Structure Algebraic Code Excited Linear Predictive (CS-ACELP) coding was developed and standardized as ITU G.729 speech coding at 8 kbps. Later, MP-CELP coder has been proposed to be a scalable coder around this bitrates. This flexible coder employs the multi-pulse excitation which the number of pulses in fixed-entry codebook is selective for bitrates scalability and multiple bitrates functionality according to the MPEG-4 CELP speech coder requirements, (Nomura et al., 1998; Chomphan, 2010b; Rahim and Islam, 2009).

In MP-CELP, amplitudes or signs for multi-pulse excitation are simultaneously vector quantized. To improve speech quality for background noise conditions, the adaptive pulse location restriction method are applied (Ozawa and Serizawa, 1998). This coder operates at various bitrates ranging from 4-12 kbps utilizing the flexibility in multi-pulse excitation coding (Chomphan, 2010b; Singh et al., 2007).

As for tonal language, such as Thai, a syllable is composed of consonants, vowels and tone (Wutiwihatchi and Furui, 2007).
The smallest structure of sounds or syllables in Thai is composed of one vowel unit or one diphthong, one, two or three consonants and a tone. The structure can be represented as illustrated in Fig. 1. Ci is initial consonant, Cf is final consonant, V is vowel and T is tone.

The significant difference between tonal and toneless language is Tone (T). In tonal language, the words of different tones yield their distinguished meaning. By using the standard speech coder such as CS-ACELP with tonal language, it showed the degraded speech quality when compared to those of toneless language. The reason is that the tone information precision is not enough for tonal language, (Chompun et al., 2000; Wutiwiwatchai and Furui, 2007).

This study proposes a bitrates scalable tonal language speech coder based on a multi-pulse based code excited linear predictive coding (Taumi et al., 1996; Ozawa et al., 1996; Al-Haddad et al., 2009). The proposed coder provides the bitrates scalabilities which is effective in multimedia communications. Moreover, this coder is improved for the tonal language speech by applying the high pitch delay resolutions to retain the tone information precision.

MATERIALS AND METHODS

**Bitrates scalable MP-CELP coder:** The operation principle for bitrates scalable MP-CELP coder can be separated into 2 parts, MP-CELP core coder and bitrates scalable tool.

**MP-CELP core coder:** The MP-CELP core coder achieves a high coding performance by introducing a multi-pulse vector quantization as depicted in Fig. 2 (Taumi et al., 1996; Ozawa et al., 1996). The input speech of 10 ms frame is processed through Linear Prediction (LP) and pitch analysis. The LP coefficients are quantized in the Line Spectrum Pairs (LSP) domain. The pitch delay is encoded by using an adaptive codebook. The residual signal for LP and the pitch analysis is encoded by the multi-pulse excitation scheme. The multi-pulse excitation signal is composed of several non-zero pulses. The pulse positions are restricted in the algebraic-structure codebook and determined by an analysis-by-synthesis approach, (Laflamme et al., 1991; Chomphan, 2010a).

**Bitrates scalable tool:** This study uses at most 3 stages of the bitrates scalable tools according to the MPEG-4CELP requirement as illustrated in Fig. 3 (Chomphan,
Tonal language speech coder: In Thai speech, there are 5 different tones, mid(0), low(1), falling(2), high(3) and rising(4), whose characteristics are depicted in Fig. 4 (Wuttiwijatchai and Furui, 2007). Each graph represents the behavior of fundamental frequency (f0) in a period of syllable time where f0 is the inverse of pitch delay time. Though, f0 indicates the periodicity of voice. Investigating the difference between Thai male and Thai female f0 behaviors, Thai female f0 change rate is almost all more than Thai male f0’s, (Thathong et al., 2000). This is why the Thai female speech quality encoded by CS-ACELP coder is lower than the Thai male speech quality (Chompun et al., 2000). Hence, detecting f0 with high precision yields the improvement of the tonal language speech quality. Since pitch delay (or f0) significantly involves in tone of tonal language, this study proposes an improvement of the bitrates scalable MP-CELP coder by applying the High Pitch Delay Resolutions (HPDR) technique to the pitch analysis of the core coder. The HPDR is done by including the pitch fraction analysis within the conventional coder tool (1 stage). The effectiveness of the high pitch delay resolutions applied to the conventional coder was evaluated using average segmental SNRs and MOS scores. Comparison tests of each grouped bitrates were conducted and shown in Table 3 and 4.

In order to find the adaptive excitation for the proposed technique, the FIR filter based on a Hamming windowed sin(x)/x function truncated at ±11 and padded with zeros at ±12 is adopted to weight the excitation in the pitch fraction analysis.

RESULTS

The coding quality of the proposed coder was evaluated subjectively and objectively by using 36 tested sentences from 10 men and 10 women, some of them were shown in Table 2.

Table 1: Objective speech quality (SegSNR)

| Stage of scalability | Grouped bitrates (pbs) | 5600+ | 6400+ | 7200+ | 8000+ |
|----------------------|------------------------|-------|-------|-------|-------|
| Male                 | Conv.                  | 7.45  | 7.81  | 8.31  | 9.06  |
| HPDR 1.2−1           | 7.61                   | 7.93  | 8.79  | 9.45  |
| HPDR 1.3−1           | 7.70                   | 8.01  | 8.87  | 9.59  |
| HPDR 1.4−1           | 7.86                   | 8.04  | 8.90  | 9.61  |
| Female               | Conv.                  | 7.26  | 7.66  | 8.18  | 8.69  |
| HPDR 1.2−1           | 7.35                   | 7.88  | 8.21  | 9.23  |
| HPDR 1.3−1           | 7.61                   | 8.01  | 8.82  | 9.38  |
| HPDR 1.4−1           | 7.70                   | 8.06  | 8.85  | 9.41  |

In Table 1, the objective speech quality is shown as the average segmental SNRs and MOS scores. As for bitrates scalable tool, each stage increases the bitrates of 800 bps. Though, the 1, 2, 3 stages of scalability operate at the total bitrates of 6400, 7200 and 8000 bps respectively.

The bitrates scalable tool encodes the residual signal produced at the MP-CELP core coder utilizing the multi-pulse vector quantization. Adaptive pulse position control is employed to change the algebraic-structure codebook at each excitation-coding stage depending on the encoded multi-pulse excitation at the previous stage. The algebraic-structure codebook is adaptively controlled to inhibit the same pulse positions as those of the multi-pulse excitation in the MP-CELP core coder or the previous stage. The pulse positions are determined so that the perceptually weighted distortion between the residual signal and output signal from the scalable tool is minimized. The LP synthesis and perceptually weighted filters are commonly used for both the MP-CELP core coder and the scalable tool.

For this conventional coder, the bit allocation is shown in Table 1. The bitrates of core coder is 5600 bps. As for bitrates scalable tool, each stage increases the bitrates of 800 bps. Though, the 1, 2, 3 stages of scalability operate at the total bitrates of 6400, 7200 and 8000 bps respectively.

"Table 1: Bit allocation for the conventional coder"

| Parameter | MP-CELP | Bitrates scalable tool |
|-----------|---------|------------------------|
| LSP       | 18      | 1×2                    |
| Pitch delay| 16      | 4×2                    |
| Multi-Pulse| 5×2     |                        |
| Gain      | 7×2     |                        |
| Total     | 56      | 8                      |

Fig. 4: The f0 characteristic of 5 tones in Thai

Table 2: Thai tested sentences (examples) 0-4 at each word represent tone of Thai

| Order | Tested sentences                                           |
|-------|------------------------------------------------------------|
| 1     | น่า แต่ น่า แสดง ว่า รูป นักศึกษา ที่ ศูนย์ สถาบัน บัณฑิตศึกษา (kha4 hae4 laa1 liu3 noo4 phi2 bo:t1) |
| 2     | คน ที่ พบ ต่าง ดนตรี ตาม เสียง (kho4 thom2 ba4 pi1 u1 at1 tu1 ao4 wa2 2 keng1) |
| 3     | คำ วา เดิม หา วา ดา ส่ม (Kha10 wa2 2 tr1 apl1 phx1 0 wa2 2 t11 lum2) |
| 4     | พูด ไทย แปล บรรยาย ตัว (phua42 nan3 doo10 ra1 plx1 tu1 ao4) |
| 5     | เช้า พบ ญาติ อย่าง คำ (kha4 pen0 ja22 tan0 pha10) |
| 6     | นั่น จะ อาวุธ ถูก นั่น (nai4 mg3 ca17 aw10 waw21 an0 nan3) |
| 7     | นี่ กลาย ผู้ สำนึก เลือก ริบท (kha10 jai1 sak1 la1 jx1 au4 thi2 kha10 nm4) |

Table 3: Thai tested sentences (examples) 0-4 at each word represent tone of Thai

In Table 2, the tested sentences are 5 different tones, mid(0), low(1), falling(2), high(3) and rising(4), whose characteristics are depicted in Fig. 4 (Wuttiwijatchai and Furui, 2007). Each graph represents the behavior of fundamental frequency (f0) in a period of syllable time where f0 is the inverse of pitch delay time. Though, f0 indicates the periodicity of voice. Investigating the difference between Thai male and Thai female f0 behaviors, Thai female f0 change rate is almost all more than Thai male f0’s, (Thathong et al., 2000). This is why the Thai female speech quality encoded by CS-ACELP coder is lower than the Thai male speech quality (Chompun et al., 2000). Hence, detecting f0 with high precision yields the improvement of the tonal language speech quality. Since pitch delay (or f0) significantly involves in tone of tonal language, this study proposes an improvement of the bitrates scalable MP-CELP coder by applying the High Pitch Delay Resolutions (HPDR) technique to the pitch analysis of the core coder. The HPDR at pitch fraction delay time. Though, f0 indicates the periodicity of voice.
Table 4: Subjective speech quality (MOS Score)

| Stages of scalability | none | 1   | 2   | 3   |
|-----------------------|------|-----|-----|-----|
| Grouped bitrates (pbs)| 5600+| 6400+| 7200+| 8000+|
| Male                  |      |     |     |     |
| Conv.                 | 3.12 | 3.18| 3.28| 3.35|
| HPDR.1/2              | 3.18 | 3.22| 3.30| 3.36|
| HPDR.1/3              | 3.21 | 3.30| 3.32| 3.38|
| HPDR.1/4              | 3.22 | 3.33| 3.34| 3.39|
| Female                |      |     |     |     |
| Conv.                 | 3.09 | 3.11| 3.20| 3.31|
| HPDR.1/2              | 3.13 | 3.16| 3.24| 3.33|
| HPDR.1/3              | 3.16 | 3.23| 3.27| 3.34|
| HPDR.1/4              | 3.19 | 3.28| 3.30| 3.36|

**DISCUSSION**

For the objective test (SegSNR), the results showed that both male and female speech quality, every grouped bitrates, the HPDR at pitch fraction of 1/4 gave the maximum value. The order of speech quality from the best to the worst was 1/4’s, 1/3’s, 1/2’s and conventional’s respectively. For the subjective test (MOS score), the results were corresponding to those of the objective test.

From the experimental results, the more high resolution be used the more speech quality be obtained. This indicates that the proposed HPDR technique brings the better pitch precision which causes an improvement of the coding quality for tonal language.

**CONCLUSION**

In this study, a modification of bitrates scalable tonal language speech compression has been proposed. The compression algorithm consists of a MP-CELP core coder and the bitrates scalable tools. The high pitch delay resolutions are applied to adaptive codebook of core coder for tonal speech quality improvement. The results show that the coding quality of the proposed coder is better than the conventional coder for Thai language. The proposed approach can support a number of coding rates.

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