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Recording Quality of Smartphone for Acoustic Analysis

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ー **ABSTRACT** ー

Introduction：The U-health system supports health care services for prevention, diagnosis, medical treatment, and post-health management. Currently, various medical service systems such as telemedicine, emergent medical treatment, and private health monitoring are in use. Diagnosis of patient with glottic cancer using pathologic voice is one of private health monitoring. **Aim**：The purpose of this study was to compare the quality of pathologic voice in various recording methods using smartphone. **Methods**：Voice samples were collected simultaneously from 28 patients with glottic cancer using nine recording methods. Acoustic analysis was performed to assess the parameters including jitter, shimmer, noise to harmony, and cepstral prominence peak of voice quality using MDVP and ADSV. **Results**：Correlations were calculated among the various parameters. All of the measured acoustic parameters showed the highest correlation to CPP. The high correlation method used for the iPhone involved a combination of a professional recording app and a unidirectional microphone, while the high correlation method used for an Android phone involved a combination of a professional recording app and an internal microphone. **Conclusions**：The present findings indicate that the smartphone devices of both iPhone and Android phone were useful for recording and analyzing pathologic voice for evaluation in clinical practice. We confirmed the possibility of using smartphone-based recording for spectral and cepstral analysis of pathologic voice. The value of the mobile device and its applications may be in its ability to provide meaningful, accurate, and timely informative guidance to the clinician by improving the availability and quality of patient's findings. **(J Clinical Otolaryngol 2016;27:286-294)**

KEY WORDS：Smartphone · Voice recording · Android · iOS · MDVP · ADSV.

Introduction

Acoustic analysis of voice has been found to be a useful tool for evaluating voice disorders and conditions. However, the clinical application of acoustic voice analysis is limited by various methodological considerations.[1] Factors limiting the validity and possibility of voice analysis were derived from variations in methods of analysis, type of microphone, microphone placement, recording system,[2] and environment of sample acquisition.[3]

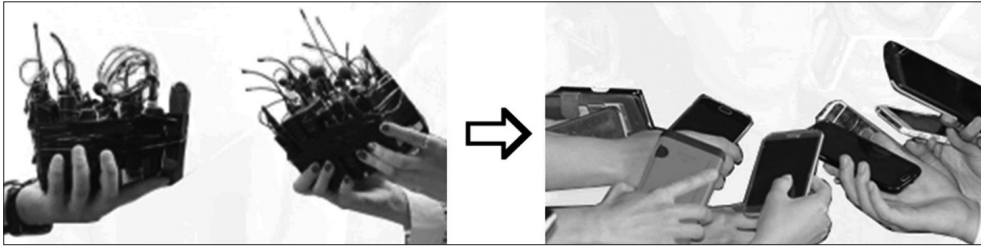Recent advancements in digital technology have

Fig. 1. Change of trend in the interview scene by the recording equipment development. Smartphone has replaced the role of the voice recorder in various situations.

expanded access to mobile and user-friendly devices capable of recording voice signals in lossless audio formats and sending the digitized audio files through the mobile network. Previous studies have been performed that have recorded and analyzed voices using smart phones as opposed to voice recorders (Fig. 1). This mainstream technology has a great potential to promote the practical effect and timeliness of acoustic voice analysis. The use of smartphones for clinical applications has gained interest due to the advancement of digital technology and availability of a wide sampling rate (e.g., 11,000−96,000 Hz) ; it may demonstrate the advantage of preserving the acoustic characteristics without a loss of quality for voice monitoring.

Lin, Hornibrook, & Ormond (2012) compared the pre- and post-op samples of patient voices through both iPhone recordings and PC-based recordings.[4] Additionally, Hornibrook, Lin, & Ormond (2011) evaluated the adequacy of an iPhone for voice recording and demonstrated the usefulness of an iPhone-based acoustic analysis for identifying voice aberrancy and checking voice changes after phonosurgery.[5]

Voice recordings from glottic cancer patients were used to evaluate the recording capabilities of smartphones for quantifying voice disturbance in voice disorders. Voice recordings of speaker output from the patient voice samples were taken with smartphones, i.e., iPhone and Android phone. Sony voice recorder and Computerized Speech Lab (CSL) were used as the digital recording systems for comparison. The purpose of the study was to test the hypothesis that smartphone recordings could be effectively used

for acoustic voice assessment.

Materials and Methods

Voice sample recording

Researchers obtained pathologic voice samples from individuals referred to the Department of Otorhinolaryngology-Head and Neck Surgery, Pusan National University Hospital. Voice samples were acquired during the first visit. The voice samples of glottic cancer patients comprised 28 voice audio files, consisting of samples from 28 men aged between 55 and 89 years (mean=67.9, SD=8.8). Participant inclusion criteria included glottic cancer patients who had been identified through videoendoscopy, laryngeal stroboscopy, and biopsy. Additionally, participants were screened to exclude individuals with no history of speech and hearing problems and no neurological trauma or psychological illness.

Instrumentation

For the study, an iPhone5S (Apple, USA) and a Galaxy S5 (Samsung, Korea), with an internal microphone or unidirectional microphone, were used for audio recording (setting : PCM, 44.1 kHz sampling rate, 16 bit) with the internal recording app and professional recording app (Fig. 2). An additional recording system, Computerized Speech Lab (Kay Pentax, Model), was also used for comparison of the various methods.

The microphone signals recorded via the smartphone device were saved as 'M4A' files, which were of an audio file format employing a codec designed to provide lossless encoding. The 'GoldWave' soft-
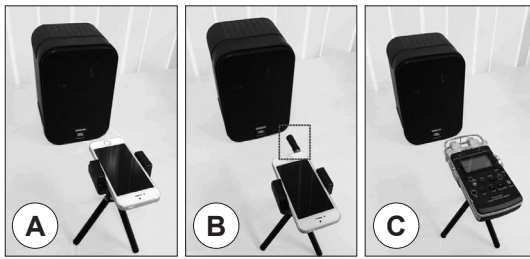
Fig. 2. Setup for a device recording in a conference room. The clean recording is played through the loudspeaker and recorded on a smartphone, capturing the noise and reverberation of the room as well as the limitations of the recording hardware. A : The smartphone signals were recorded with the smartphone placed in front of personal computer's mono speaker at a distance of approximately 15 cm. B : Smartphone recording setting with unidirectional microphone (*red dotted square*). C : Sony voice recorder setting.

ware (GoldWave Inc., Canada) was used to convert iPhone- and Android phone-recorded 'M4A' files into 'WAV' files ('iPhone signals'). The sampling rate was set at 44.1 kHz. The microphone signals recorded through the professional recording app were directly digitized and saved as 'WAV' files ('comparison signals'). The sampling rate was set at 48.0 kHz in iPhone's professional recording app and at 44.1 kHz in Android's professional recording app. The Sony voice recorder signals were saved as 'WAV' files and set at 44.1 kHz. The CSL acoustic analysis software was used to play back and process all of the smartphone and comparison signals to extract the acoustic measures.

Recording methods were included as follows : 1 (i1), Internal recording app (iPhone) with internal microphone ; 2 (i2), Internal recording app (iPhone) with uni-directional microphone ; 3 (i3) : professional recording app (iPhone) with internal microphone ; 4 (i4), professional recording app (iPhone) with uni-directional microphone ; 5 (SONY), Sony voice recorder ; 6 (A1), Internal recording app (Android) with internal microphone ; 7 (A2), Internal recording app (Android) with uni-directional microphone ; 8 (A3), professional recording app (Android) with internal microphone ; 9 (A4), professional recording app (Android) with uni-directional microphone.

Procedure

Each voice sample was recorded in a quiet room with the ambient noise level kept below 40 dB. The smartphone signals were recorded with the smartphone placed in front of the personal computer's mono speaker at a distance of approximately 15 cm. This protocol was used for the nine methods with iPhone and Android phones. First, using the internal recording app with either an internal microphone or unidirectional microphone ; second, using a professional recording app with either an internal microphone or unidirectional microphone ; third, using Sony voice recorder. For the sustained phonations, three of the relatively more stable replicate recordings were selected for analysis from five replicates, and 1-second segments were cut to eliminate the offset and onset of phonation. After the smartphone and microphone were secured in place, the voice sample audio file was played to record according to the nine methods while the experimenters activated the recording systems and saved the signals in digital audio files.

M4A-WAV conversion

The present authors checked the changes in the waveform using GoldWave program according to M4A-WAV conversion. The two signal patterns were compared with the 5 ms duration of the signal. As a result of the comparison of the two waveforms, there was no change in the waveform. Additionally, there was no difference between the acoustic values before and after conversion modification.

Waveform analysis

Each of the saved or converted 'WAV' files was displayed on the computer screen, with time waveforms shown in one channel. For waveform analysis, Praat software was used.

Spectral analysis

For voice quality analysis, Multidimensional Voice Program Analysis (MDVP) was used to derive the fol-

lowing measures from the sustained vowel : average fundamental frequency (F0), percent jitter, percent shimmer, and noise-to-harmonic ratio (NHR). Spectrum analysis showed differences based on the microphone type between the low frequency area and high frequency area. Due to a frequency response range of 100−12,000 Hz in the unidirectional microphone, it could not capture the signal of over 12,000 Hz. As frequency response range included the range of human voice information, there was no difficulty obtaining a voice signal without any loss of voice information.

Cepstral analysis

Cepstral analysis was measured using Analysis of Dysphonia in Speech and Voice (ADSV, model 5109 ; KayPENTAX, Montvale, NJ) from the sustained vowel : cepstral prominence peak (CPP).

Statistical analysis

Statistical analysis was conducted for spectral analysis and cepstral analysis with recording types. The Kolmogorov-Smirnov test was used to assess the normality of the F0, jitter, shimmer, NHR, and CPP values of the recording methods. To find the most similar method to CSL, correlations between each recording method (with the measure of voice quality parameters and cepstral parameters) were calculated with the SPSS of Pearson or Spearman at a significant level inferior to 5% ($p < 0.05$). The ranges of correlation were as follows : < 0.3 poor, 0.3-0.5 fair, 0.5−0.7 mild, and 0.7−0.9 strong.

Results

Waveform analysis

Regardless of the recording app, the unidirectional microphone did not smooth the peak of the waveform. Waveform signals could be captured without smoothing irregular waveform patterns. In other words, it expressed the original waveform patterns and did not modify the waveform signals.

Spectral analysis of voice signal (MDVP)

In the results of Kolmogorov-Smirnov test, F0 and percent shimmer showed normality, while percent jitter and NHR did not show normality. Table 1 shows F0 values for the sustained vowel segment for 28 voice samples of glottic cancer patients.

All F0 values of the recording methods revealed a statistically significant strong correlation between F0 and CSL. In the case of iPhone type, the highest correlating method was using the internal recording application with the internal microphone (r=0.935). Furthermore, the highest correlating method in Android type was using the professional recording application with the internal microphone (r=0.977). Second, most percent jitter values of the recording methods revealed a statistically significant strong correlation between percent jitter value and CSL (Table 2).

In the case of iPhone type, the highest correlation method was using the professional recording application with the unidirectional microphone (r=0.839).

Table 1. Results of correlations among each recording method for average fundamental frequency

	F0i1	F0i2	F0i3	F0i4	Sony	F0A1	F0A2	F0A3	F0A4
Pearson's r	.935**	.887**	.913**	.771**	.972**	.967**	.976**	.977**	.951**
p	.000	.000	.000	.000	.000	.000	.000	.000	.000

∗∗ : Significant at 0.01 level (two-tailed)

Table 2. Results of correlations among each recording method for percent jitter

	jiti1	jiti2	jiti3	jiti4	Sony	jitA1	jitA2	jitA3	jitA4
Spearman's r	.660**	.831**	.773**	.839**	.748**	.701**	.566**	.877**	.744**
p	.001	.000	.000	.000	.000	.000	.007	.000	.000

∗∗ : Significant at 0.01 level (two-tailed)

Table 3. Results of correlations among each recording method for percent shimmer

	nhri1	nhri2	nhri3	nhri4	Sony	nhrA1	nhrA2	nhrA3	nhrA4
Spearman's r	.814**	.873**	.854**	.837**	.734**	.780**	.774**	.886**	.864**
p	.000	.000	.000	.000	.000	.000	.000	.000	.000

** : Significant at 0.01 level (two-tailed)

Table 4. Results of correlations among each recording method for noise-to harmonic ratio (NHR)

	nhri1	nhri2	nhri3	nhri4	Sony	nhrA1	nhrA2	nhrA3	nhrA4
Spearman's r	.814**	.873**	.854**	.837**	.734**	.780**	.774**	.886**	.864**
p	.000	.000	.000	.000	.000	.000	.000	.000	.000

** : Significant at 0.01 level (two-tailed)

Table 5. Results of correlations among each recording method for cepstral prominence peak (CPP)

	cppi1	cppi2	cppi3	cppi4	Sony	cppA1	cppA2	cppA3	cppA4
Pearson's r	.986**	.994**	.994**	.996**	.996**	.995**	.989**	.996**	.992**
p	.000	.000	.000	.000	.000	.000	.000	.000	.000

** : Significant at 0.01 level (two-tailed)

Furthermore, the highest correlation method in Android type was using the professional recording application with the internal microphone (r=0.877). Third, all percent shimmer values of the recording methods revealed statistically significant strong correlations between percent jitter value and CSL (Table 3).

In the case of iPhone type, the highest correlation method was using the internal recording application with the internal microphone (r=0.853). Furthermore, the highest correlation method in Android type was using the professional recording application with the internal microphone (r=0.919). Fourth, most NHR values of the recording method revealed statistically significant strong correlations between the NHR value and CSL (Table 4).

In the case of iPhone type, the highest correlation method was using the internal recording application with the unidirectional microphone (r=0.873), and the highest correlation method in Android type was using the professional recording application with the internal microphone (r=0.886). The average correlation of Android was higher than iPhone at F0 and percent shimmer, but the average correlation of iPhone was higher than Android at percent jitter and NHR (Fig. 3).

Cepstral analysis of voice signal (ADSV)

Table 5 showed cepstral prominence peak (CPP) values of the sustained vowel segment for 28 voice samples of glottic cancer patients. From these results, all CPP values of the recording methods revealed statistically significant strong correlations between CPP value and CSL. In the case of iPhone type, the highest correlation method was using the professional recording application with the unidirectional microphone (r=0.996). Furthermore, the highest correlation method in Android type was using the professional recording application with the internal microphone (r=0.996). The average correlation of Android (mean r=0.955) was higher than iPhone (mean r=0.929) (Fig. 3).

Discussion

We investigated the reliability of acoustic measurements using smartphones. Recently, the use of smartphones for clinical applications has gained increasing scientific interest owing to developments in digital technology. Smartphones and mobile devices are providing the convenience of portability as well as multifunctionality within one device.[6] The growing num-
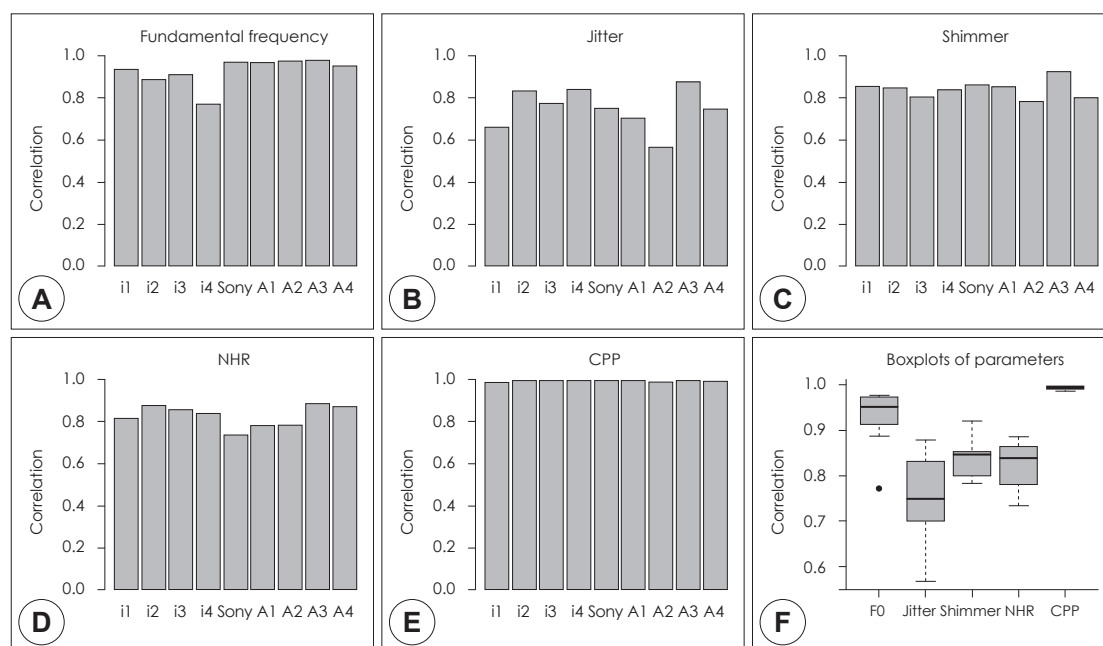
Fig. 3. Result of correlation to acoustic value of CSL. A : Correlation to value of CSL in fundamental frequency (F0). B : Correlation to value of CSL in jitter. C : Correlation to value of CSL in shimmer. D : Correlation to value of CSL in NHR. E : Correlation to value of CSL in CPP. F : boxplot of correlation results in acoustic parameters. Significant correlations were found for all measured acoustic parameters, among them, CPP showed the highest correlation. i1 : Internal recording app (iPhone) with internal microphone, i2 : Internal recording app (iPhone) with uni-directional microphone, i3 : professional recording app (iPhone) with internal microphone, i4 : professional recording app (iPhone) with uni-directional microphone. SONY : Sony voice recorder, A1 : Internal recording app (Android) with internal microphone, A2 : Internal recording app (Android) with uni-directional microphone, A3 : professional recording app (Android) with internal microphone, A4 : professional recording app (Android) with uni-directional microphone.

ber of applications allows for extensive possibilities in terms of the variety of human needs.[7]

We could quantify the severity of the voice disorders through the non-invasive acoustic analysis. We measured the degree of voice signal periodicity using time-based analysis[8] or frequency-based analysis.[9] Time-based perturbation was not suitable for acoustic analysis in the signals, defined by aperiodicity/chaos.[10]

Vogel et al. (2014) recorded the voice samples simultaneously using four acquisition methods including the disc recorder, landline telephone, smartphone, and laptop PC. Additionally they measured the voice quality using SpeechTool and MDVP.[11] Uloza et al. (2015) identified the reliability of acoustic voice parameters obtained using smart phone (SP) microphones with two microphones and reported that these methods are helpful for early diagnosis of voice disorders.[12]

Previous studies reported that time-based analysis could effectively measure acoustic parameters such as jitter, shimmer and noise to harmony (NHR) of the voice sample from smartphone-based recordings.[11] This traditional analysis method had limitations of low reliability in severe voice quality and non-periodic phonation.

In order to overcome the limitations, cepstral analysis, which could analyze the harmony of spectrum, was introduced. CPP and related measures showed high correlation to breathiness[13] and additional discriminative potential for hoarseness.[14] But those presented relatively less correlation to roughness.[15] Additionally, CPP-related measures showed strong correlations to dysphonia severity and auditory perceptual judgments.[16]

We conducted the smartphone recordings with in-

ternal/external microphones and measured the spectral and cepstral parameters. Results indicated that cepstral analysis had higher reliability than spectral perturbation analysis in evaluating severe voice quality changes of glottis cancer patients. Significant correlations were found for all measured acoustic parameters, among them, CPP showed the highest correlation.

In the acoustic analysis, it is important to select appropriate microphone types as acoustic parameters might be changed according to the microphone types. For the evaluation and analysis of voice, characteristics such as type of the microphone, direction of the microphone, frequency response, and distance of the microphone are important to consider.[17] Choi (2013) applied survey research on job analysis of speech language pathologists. Of these speech language pathologists, 24 individuals (83%) used unidirectional dynamic microphones such as Shure PG48 or SM48/58.[18] The unidirectional dynamic microphone has the characteristic of absorbing sound from the front of the microphone, so that environmental noise can be reduced ; thus, improving its usefulness in clinical applications.[19] However, use of this microphone can create spectrum parameter values such as a soft phonation index that is distorted in CSL due to approximation effect .

A previous study evaluated voice analysis using smartphones connected to an external microphone, but this study did not consider the smartphone internal microphone.[20] To understand the efficacy of smartphones for acoustic evaluation in dysphonia, studies that could compare the internal microphone in smartphones with unidirectional microphones and analyze two microphones should be conducted. However, few of these studies exist.

In the MDVP analysis of laryngeal cancer voice samples, it is difficult to detect the periodicity of voice, so the reliability was relatively reduced in MDVP analysis. If periodicity of voice was not detected, periodic parameters such as jitter, shimmer, and NHR were measured directly from sound waveform, or the spectrum could not be analyzed. In severe dysphonia, it is

difficult to detect periodicity ; this makes the results of acoustic analysis inconsistent. In contrast, CPP means prominence of cepstrum peaks and degree of periodicity and is useful in assessment of severe voice quality. The values of CPP are calculated from first rahmonic components. Because the values of quefrency in the first peak of rahmonic mean periodicity of the voice signal, the values of periodicity in voice signal could be calculated.

In the iPhone and Android phone, it is possible to record the voice because an internal recording application is included ; however, it had some limitations compared to the professional recording application. First, format of the voice signals should be converted into MP3, WAV format. Second, the functions such as high quality of sound and fine control of filtering are not ideal, making it difficult to analyze the voice signal for acoustic evaluation. Professional recording application is convenient and high quality sound can be acquired. It is also possible to select file formats. For the internal recording application, conversion of the file format is needed because it saves voice signal as its own codec and file format. For the professional recording application, it could save the voice signal as WAV, AAC, or MP3 file format and allow selection of bit-rate and quality of sound. Using the AAC file format, it is possible to analyze the voice signal for acoustic evaluation, which is useful when the capacity of PCM runs out. The smartphone was affected by the sound pressure of the microphone and internal and/or around noise. However, the voice recorder could record sound consisting of high pressure, and it is relatively unaffected by surrounding noise. Although it can record high quality sound, it is expensive and is not portable. Further, in some parameters, correlations between voice recorder and CSL were lower than other analysis methods. The results of this study present the efficacy of smart phone use for clinical applications. Clinicians could conveniently evaluate the voice changes of patients and the patients could verify that the voice is good or bad.

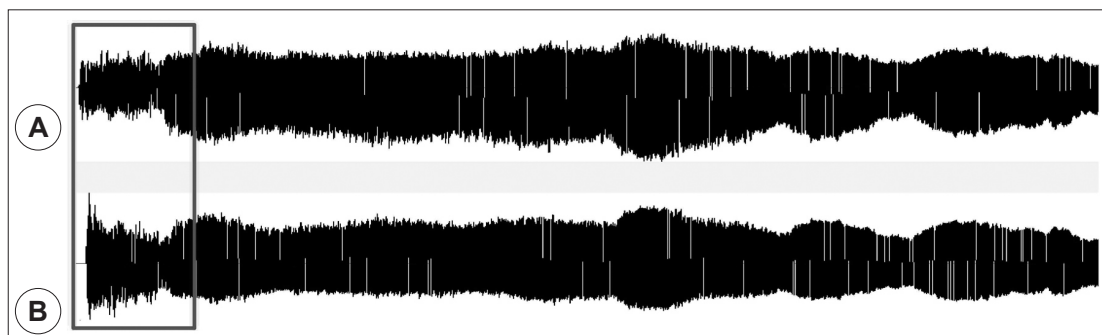There are some limitations of smartphone record-

Fig. 4. Examples of distortion of the input voice signal. A : Original input voice signal. B : distortion of the input voice signal due to auto gain control (AGC). Original voice signal was changed as distorted waveform (red solid square) due to AGC of smartphone recording input. It was important to select a stable voice section of the input signal from smartphone for high reliability in acoustic analysis.

ing in clinical practice. First, researchers must select a steady voice section of the signal during voice analysis with a smartphone because of the fade-in and fade-out of the input signals. Particularly, researchers should be analyzed in consideration of these characteristics in the sound spectrogram study using smartphone recording method (Fig. 4). Second, recording voice during a phone call makes it difficult to perform reliable voice analysis for features such as jitter and shimmer due to distortion of obtained voice signals. We may consider that additional technology is required to resolve this limitation.

Conclusion

In the results of this study, it is possible to input consistent voice signal regardless of the types of voice input. Additionally, the selection of methods in analysis is important. In an environment that could control noise, it is possible to record voice analysis using a smartphone. If the recording is performed in a quiet environment while maintaining proper distance from the microphone and proper phonation, the reliability of analysis is ensured. This method should be implemented in spectral and cepstral analysis and the results should be considered.

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