A REAL-TIME FILLED PAUSE DETECTION SYSTEM FOR SPONTANEOUS SPEECH RECOGNITION

Masataka Goto  Katunobu Itou  Satoru Hayamizu
Machine Understanding Division, Electrotechnical Laboratory
1-1-4 Umezono, Tsukuba, Ibaraki 305-8568 JAPAN.
\{goto, kito, hayamizu\}@etl.go.jp  http://www.etl.go.jp/\~goto/

ABSTRACT
This paper describes a method for automatically detecting filled (vocalized) pauses, which are one of the hesitation phenomena that current speech recognizers typically cannot handle. The detection of these pauses is important in spontaneous speech dialogue systems because they play valuable roles, such as helping a speaker keep a conversational turn, in oral communication. Although a few speech recognition systems have processed filled pauses within subword-based connected word recognition or word-spotting frameworks, they did not detect the pauses individually and consequently could not consider their roles. In this paper we propose a method that detects filled pauses and word lengthening on the basis of small fundamental frequency transition and small spectral envelope deformation under the assumption that speakers do not change articulator parameters during filled pauses. Experimental results for a Japanese spoken dialogue corpus show that our real-time filled-pause-detection system yielded a recall rate of 84.9% and a precision rate of 91.5%. Keywords: Filled pause, Hesitation, Spontaneous speech

1 INTRODUCTION
The goal of this research is to improve the computer’s ability to understand speech to a degree that will make possible natural multimodal communication between humans and computers. This requires the computer to recognize the audio signals comprising the spontaneous speech uttered by a speaker thinking about speech contents on the fly. Hesitation phenomena, such as filled (vocalized) or unfilled (silent) pauses, word lengthening, restarts, and false starts, occur frequently in such speech. As an initial step toward dealing with those natural and inevitable phenomena, in this paper we concentrate on two frequent phenomena, filled pauses and word lengthening, because these phenomena play the same valuable roles in oral communication, such as helping a speaker hold a conversational turn and express mental and thinking states. In order to improve speech dialogue systems, we think that it is important to make good use of such roles without simply neglecting those phenomena.

Typical HMM-based speech recognizers accept only fluent read or planned speech without hesitation phenomena and have difficulty in dealing with spontaneous speech. The phone model, for example, does not work well when applied to speech with filled pauses and word lengthening because the duration of a phone tends to lengthen suddenly, and the language model is not effective enough to deal with filled pauses because the pauses can be inserted at almost arbitrary word positions. A few previous speech recognition systems have partly handled filled pauses within subword-based connected word recognition or word-spotting frameworks. One HMM-based recognizer, for example, added several frequent filler words to the system vocabulary and another one regarded filler words as out-of-vocabulary words and dealt with them by using a subword-unit based decoder for processing unknown words. Those systems, however, did not detect filled pauses individually and could not consider the roles of these pauses.

We therefore believe that it is necessary to detect filled pauses (fillers) and word lengthening in spontaneous speech by using bottom-up acoustical analysis. Previous investigations of the prosodic features of filled pauses suggested the feasibility of detecting the pauses. The report of Quimbo et al., in particular, supported the bottom-up approach of analyzing prosodic features by pointing out that human beings can, from prosodic cues, recognize filled pauses in speech that is in unfamiliar foreign language. In those investigations, however, a computational system of automatically detecting filled pauses was not built.

In this paper we propose a method for detecting filled pauses and word-lengthening phenomena in spontaneous speech. Since both these hesitation phenomena have similar acoustical features and can be considered to have the same functions in terms of oral communication, in the rest of this paper we use the term “filled pause” for both. In the following sections, we first discuss the roles of filled pauses and describe the algorithm of the method. We then show experimental results obtained using our real-time system based on the proposed method. Finally, we discuss applicability of the method in a speech recognition framework.

2 IMPORTANCE OF FILLED PAUSES
In this research, we hypothesize that the essential reason that filled pauses are inevitable in spontaneous utterances is that they are uttered when the thinking process cannot keep up with the speaking process. When the speed of speaking becomes faster than the speed of preparing its content, a speaker uses filled or unfilled pauses until the next speech content resulting from the thinking process arrives at the speaking process.
The primary utility of detecting filled pauses is that it makes it possible to improve the performance of speech recognizers by avoiding the application of typical HMM-based recognition to the filled-pause periods in spontaneous speech. Furthermore, this detection enables speech dialogue systems to make use of the following two important functions of filled pauses, which functions were also discussed in [6][7].

- Communicative functions
  In spoken dialogue, a speaker uses filled pauses to keep a conversational turn while taking enough thinking time to prepare a subsequent utterance. On the other hand, a listener hearing filled pauses usually waits for the speaker’s subsequent utterance without interrupting the turn.

- Affective and cognitive functions
  For achieving smooth dialogue by sharing mental states among interlocutors, a speaker unconsciously uses filled pauses to express mental states such as difficulty, anxiety, hesitation, and humility and also to express different thinking states, such as retrieving information from memory and seeking an expression appropriate for a listener. On the other hand, a listener interprets filled pauses as indicators for inferring speaker’s mental and thinking states. In addition, filled pauses sometimes enable a listener to predict the speaker’s subsequent utterance to some extent.

3 DETECTION METHOD

The basic idea of our method is to find acoustical features of filled pauses in speech signals by using frequency analysis. If filled pauses are, as described in the previous section, uttered while the speaking process is waiting for the next speech content from the thinking process, a speaker cannot change articulator parameters during the filled pauses because subsequent utterances have not yet been prepared. Our method hence assumes that a filled pause contains a continuous voiced sound of an unvaried phoneme, because such a sound is uttered when the vocal cords are vibrated with almost constant articulator parameters (i.e., with a constant vocal-tract shape). Typical Japanese fillers such as /ee-/ /maa-/ and /ano-/ as well as most word-lengthening sounds satisfy this assumption.

Our method accordingly detects filled pauses on the basis of the following two features:

1. Small F0 (fundamental frequency) transition
   When the tension of the vocal cords is unvaried under constant articulator parameters, the F0 of the voice remains almost constant.

2. Small spectral envelope deformation
   When the vocal tract shape is unvaried under constant articulator parameters, the spectral envelope forming the formants remains almost constant. When the deformation of the envelope is evaluated, it is necessary to eliminate the air flow’s amplitude modulation, since the air flow from the lungs may vary.

In the following, we describe the main procedure of our method (Figure 1).

3.1 Calculating Instantaneous Frequencies

The first step is to calculate the instantaneous frequency [8], the rate of change of the phase of a signal, of filterbank outputs by using the short-time Fourier transform (STFT) whose output can be interpreted as a collection of uniform-filter outputs. When the STFT of a signal \( x(t) \) with a window function \( h(t) \) is defined as

\[
X(\omega, t) = \int_{-\infty}^{\infty} x(\tau) h(\tau - t) e^{-j\omega\tau} d\tau = a + jb, \quad (1)
\]

the instantaneous frequency \( \lambda(\omega, t) \) is given by this equation [8]:

\[
\lambda(\omega, t) = \omega + \frac{\partial \psi}{\partial \omega} b - b \frac{\partial \psi}{\partial \psi} a. \quad (2)
\]

In our current implementation the input signal is digitized at 16 bit / 16 kHz, and then the STFT with a 1024-sample Hanning window is calculated by using the Fast Fourier Transform (FFT). Since the FFT frame is shifted by 160 samples, the discrete time step (1 frame shift\(^1\)) is 10 ms.

3.2 Extracting Frequency Components

The extraction of frequency components is based on the mapping from the center frequency \( \omega \) of an STFT filter to the instantaneous frequency \( \lambda(\omega, t) \) of its output [9][10][11]. By finding fixed stable points of the mapping, we can extract a set \( \Psi_f(t) \) of instantaneous frequencies of the frequency components by using the following equation [10]:

\[
\Psi_f(t) = \{ \psi \mid \lambda(\psi, t) - \psi = 0, \quad \frac{\partial}{\partial \psi} (\lambda(\psi, t) - \psi) < 0 \}. \quad (3)
\]

By calculating the power of those frequencies which is given by the STFT power spectrum at \( \Psi_f(t) \), we can define the power distribution function \( \Psi_p(\omega, t) \) as

\[
\Psi_p(\omega, t) = \begin{cases} \left| X(\omega, t) \right| & \text{if } \omega \in \Psi_f(t) \\ 0 & \text{otherwise} \end{cases}. \quad (4)
\]

\(^1\)The term time in this paper is the time measured in units of frame shift.
3.3 Estimating Fundamental Frequency

To estimate the F0 of a speaker’s voice in real-world audio signals containing background noises or music, we find the most predominant harmonic structure in the extracted frequency components by using a comb-filter-like analysis. The basic idea is to evaluate the possibility of harmonics considered, H (0.97) is an amplitude attenuation factor, and W1 (20 cent) is the standard deviation of the Gaussian distribution.

4 EXPERIMENTAL RESULTS

A real-time filled-pause-detection system based on the above method has been implemented and tested on a Japanese spontaneous speech corpus consisting of 100 utterances by five men and five women (10 utterances per subject). Each utterance contained at least one filled pause. Those utterances were excerpted from a spontaneous speech dialogue corpus [12] collected using a Wizard of OZ system and were automatically segmented by detecting each silence interval longer than 300 ms.

In our experiment the recall rate (the number of filled pauses detected correctly / the total number of filled pauses) was 84.9 percent (107 / 126) and the precision rate...
ment, we used the detected filled-pause period for dynamic phone-duration control: during the detected period we inhibited the transition from a vowel phone to the next phone.

Figure 4 shows an example of an original bad alignment result and the alignment result improved by using the filled-pause detection. Results like this suggest that when utterances contain filled pauses the performance of a typical HMM-based speech recognizer can be improved by using the filled-pause detection method.

6 CONCLUSION

We have described a method for detecting filled pauses and word-lengthening phenomena by finding a continuous voiced sound of an unvaried phoneme. The method is based on two acoustical features, small F0 transition and small spectral envelope deformation, which are estimated by identifying the most predominant harmonic structure in the input. Experimental results for a Japanese spontaneous speech corpus show that our system can detect, in real time, filled pauses with a recall rate of 84.9 percent and a precision rate of 91.5 percent.

We plan to apply our method to a speech recognizer by using not only the filled-pause period (discrete judgement) but also the filled-pause possibility value (continuous judgement). Future work will also include application of our method to English filled pauses and integration of the method with a speech dialogue system to make full use of the valuable functions of filled pauses.

REFERENCES