Automatic Judgment System for Chinese Retroflex and Dental Affricates Pronounced by Japanese Students

Akemi Hoshino and Akio Yasuda

***Abstract*—Chinese retroflex aspirates are generally difficult for Japanese students learning Chinese pronunciation. In particular, discriminating between utterances of aspirated dental and retroflex affricates is the most difficult for Japanese-speakers to learn. For the students' self-learning, the automatic judgment system was developed using a computer, so as to check the pronunciations by themselves. We extracted the features of correctly pronounced aspirated dental affricates ca[ʦ'a], ci[ʦ'i], ce[ʦ'ɤ], and cu[ʦ'u] and aspirated retroflex affricates cha[tʂ'a], chi[tʂ'i], che[tʂ'ɤ], and chu[tʂ'u] by observing the spectrum evolution of breathing power during both voice onset time and voiced period of sounds uttered by 40 Chinese native speakers. We developed a 35-channel computerized filter bank to analyze the evolution of the breathing power spectrum by using MATLAB and then automatically evaluated the utterances of the 50 Japanese students. At the same time, we asked to native Chinese speakers to evaluate the same students' utterances for the reference. Our system rejected several samples that passed the screening by the native speakers. The success rates of the system were higher than 91% and 95% for aspirated retroflex and dental affricates, respectively.**

***Index Terms*—Automatic pronunciation discrimination, Chinese aspirated retroflex and dental affricates, e-learning.**

I. Introduction

Retroflex aspirates in Chinese are generally difficult for Japanese students learning Chinese pronunciation, because the Japanese language has no such sounds. In particular, discriminating between utterances with aspirated dental and retroflex affricates is difficult for Japanese-speakers to learn. We observed a classroom of native-Japanese-speaking students of Chinese uttering aspirated retroflex sounds modeledon the examples uttered by a native Chinese instructor. These utterances were generally not produced correctly; many of them sounded like dental affricates to the instructor, which implies that students could notcurl their tongues enough to articulate correctly, because there is no retroflex sounds in Japanese affricates.

In order to check the pronunciationsof students for self-learning using a personal computer, we need to establish the criteria for the correctly pronounced syllables.

Wehave previously [1]-[5] shown that breathing power during voice onset time(VOT) is a useful measure for evaluating the correct pronunciation of Chinese aspirates. We also developed an automatic evaluation system [6], [7] for the utterances of students pronouncing Chinese aspirated affricates in accordance with the two parameters of VOT and breathing power during VOT.

Although there are several research reports on retroflex sounds [8], [9], developing report on the self-learning system of Chinese aspirated dental and retroflex affricates by CAI does not exist.

In order to develop the system to discriminate between retroflex and dental affricates automatically, we extracted the features of correctly pronounced aspirated dental affricates ca[ʦ'a], ci[ʦ'i], ce[ʦ'ɤ], and cu[ʦ'u], and the aspirated retroflex affricates cha[tʂ'a], chi[tʂ'i], che[tʂ'ɤ] and chu[tʂ'u] [10] by analyzing the spectrum of breathing power during VOT of sounds uttered by native Chinese speakers. For this purpose, we developed a computerized, 35-channel frequency filter bank. We found that the main difference between aspirated dental and retroflex affricates appeared in the spectrogram of breathing power during VOT [11].

To improve the discrimination of these affricates, we extracted the features of correctly pronouncing aspirated dental and retroflex affricates by analyzing the frequency spectrum of breathing power both during VOT and inside the voiced period of sounds, and established improved evaluation criteria on this basis. Below, we discuss the results in terms of how successfully they discriminate between aspirated dental and retroflex affricates pronounced by Japanese students.

We will continue to improve our pronunciation learning system by applying it to other Chinese aspirated affricates.

The Chinese in this paper is Standard Chinese and/or Modern Standard Chinese (Putonghua),based on the Beijing dialect.

II. Difference between Aspirated Dental Affricate and Aspirated Retroflex Affricates

The affricate is a complex sound generated by simultaneously articulating explosive and fricative sounds as one sound with the same point of articulation.

In this section, we define the distinctive feature that discriminates between the dental affricate [ʦ'] and retroflex one [tʂ'] by examining the spectrogram of the pairs ca[ʦ'a] - cha[tʂ'a], ci[ʦ'i] - chi[tʂ'i], ce[ʦ'ɤ] - che[tʂ'ɤ], and cu[ʦ'u] - chu[tʂ'u] uttered by a native Chinese speaker.

Fig. 1 shows the temporal evolution of spectrograms of the aspirated retroflex sound cha[tʂ'a] (left) and the aspirated dental sound ca[ʦ'a] (right) uttered by a Chinese speaker. The

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Akemi Hoshino is with Toyama National College of Technology, 1-2 Ebie, Neriya, ImizuCity, Toyama, 933-0293 Japan (e-mail: hoshino@nc-toyama.ac.jp).

Akio Yasuda is with Tokyo University of Marine Science and Technology, 2-1-3 Etchujima, Koto-ku, Tokyo, 135-8533 Japan (e-mail: yasuda@kaiyodai.ac.jp).

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lower part of the figure shows the waveform of the voltage evolution as picked up by a microphone. The ordinate, extended upward, shows the frequency component and the shade of the stripes, implying the approximate power level at the respective times and frequencies. The aspirate appears in the brief interval at the right of the spectrogram of ca[ʦ‘a], indicated by the light, thin vertical stripes during VOT, between the stop burst and the onset of vocal fold vibrations followed by a vowel sound. This time interval is called the VOT [12], [13], in this case it is long, 160 ms. Although slightly darker stripes appear between 2500 and 5000 Hz and 70 and150 ms, the temporal variation in breathing power during VOT is not significant.

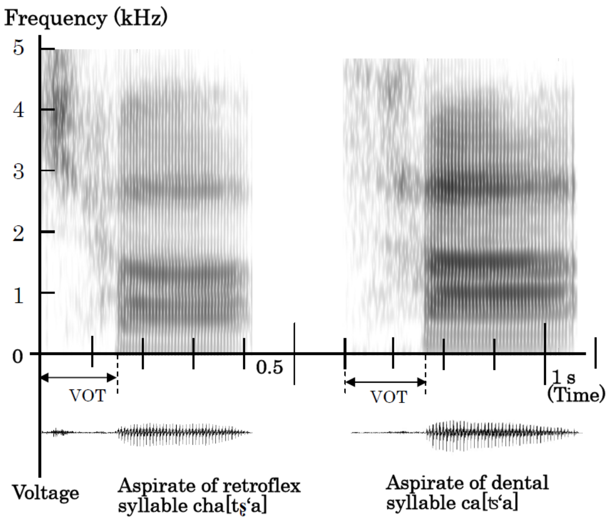

Fig. 1. Spectrograms of retroflex aspirate affricate cha[t‘a] (left) and dental aspirated affricate ca[‘a] (right) pronounced by Chinese speaker.

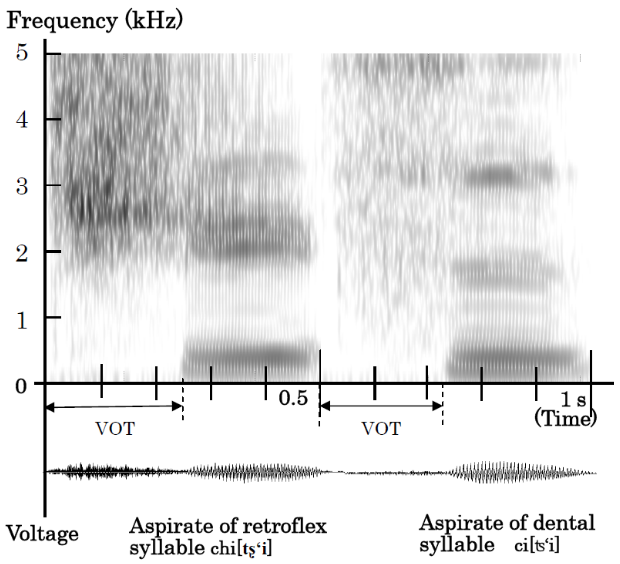

Fig. 2. Spectrograms of retroflex aspirate affricate chi[t‘i] (left) and dental aspirated affricate ci[‘i] (right), pronounced by a Chinese speaker.

The left spectrogram represents the aspirated retroflex sound cha[tʂ‘a] as uttered by a Chinese speaker. The VOT was long, 150 ms. The dark vertical stripes in the upper left were observed between 2500 and 5000 Hz in frequency, during 0 - 70 ms of VOT. This is caused by friction of airflow during breath release, arising at a spot between the curled tongue and the posterior alveolar ridge. The large amount of energy that builds up in the mouth dissipates at an early stage of VOT and generates a large amount of breathing power there.

The thick horizontal bands in the voiced period on the right part of the spectrogram represent the formants that help listeners discriminate between the three dental affricates. The criteria for discrimination are discussed later.

Fig. 2 shows the temporal variation in the spectrograms of the aspirated retroflex sound chi[tʂ‘i] (left) and the aspirated dental sound ci[ʦ‘i] (right), uttered by a Chinese speaker. The VOT of the aspirated dental sound ci[ʦ‘i] was long, 225 ms, as seen on the right. The uniform and rather light colored vertical bands show that breathing power was rather steady during VOT.

The left spectrogram shows the aspirated retroflex sound chi[tʂ‘i]. VOT was long, 250 ms. Throughout almost the entire VOT, dark vertical stripes were observed in the frequencies between 2000 and 5000 Hz. This is due to friction at the breath release, which arises at a spot between the curled tongue and the posterior alveolar.

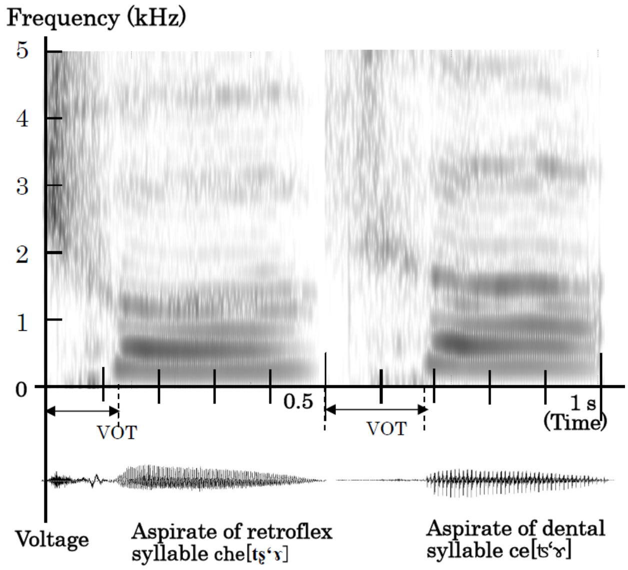

Fig. 3. Spectrograms of retroflex aspirate affricate che[t‘] (left) and dental aspirated affricate ce[‘]] (right) pronounced by a Chinese speaker.

Fig. 3 shows the temporal variation in the spectrograms of the aspirated retroflex sound che[tʂ‘ɤ] (left) and the aspirated dental sound ce[ʦ‘ɤ] (right) as uttered by a Chinese speaker. The VOT of ce[ʦ‘ɤ] was long, 180 ms. Stripes above 2000 Hz are darker and imply slightly stronger breathing power there.

For the frequencies lower than 1200 Hz in the VOT, the vertical stripesare light indicating weak breathing power. The distinctive feature of retroflex aspirated affricates is non-uniform frequency and spectra during VOT, whereas aspirated dental ones have a rather uniform spectrum, as compared to the rather uniform spectrum for aspirated dental affricates, shown in the right spectrogram.

Fig. 4 shows the temporal evolution of spectrograms of the aspirated retroflex sound chu[tʂ‘u] (left) and the aspirated dental sound cu[ʦ‘u] (right) as uttered by a Chinese speaker. The VOT of cu[ʦ‘u] was long, 185 ms, as seen on the right. Stripes above 1300 Hz are darker, implying slightly stronger breathing power there. Although darker stripes appear between 0 and 300 Hz frequency and from 80 to 120 ms VOT, the temporal variation in breathing power across VOT as a whole is not significant. The left spectrogram is for the aspirated retroflex sound chu[tʂʻu]. VOT is long, 190 ms. Dark vertical stripes are observed between 3500 and 5000 Hz in frequency and from 0 to160 ms VOT. They are caused by friction of breath during breath release, arising at a spot between the curled tongue and posterior alveolar position.

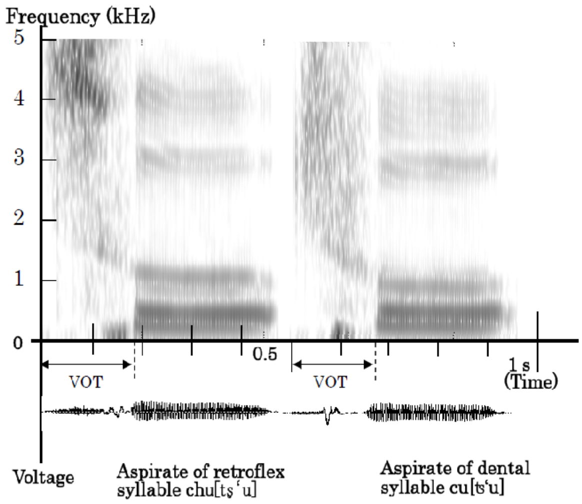

Fig. 4. Spectrograms of retroflex aspirate affricate chu[tʻu] (left) and dental aspirated affricate cu[ʻu](right) pronounced by a Chinese speaker.

III. Automatic Measurement of VOT and Breathing Power

We have shown that correct utterance of retroflex and dental aspirated affricates is closely related to the frequency spectrum in the VOT period.

Previously, we have developed an automatic measurement system for VOT and breathing power using a personal computer containing a 35-channel frequency filter bank, designed with MATLAB, in which the center frequency ranges from 50 to 6850 Hz with a bandwidth of 200 Hz [6], [7].We can extract the spectral features of aspirated retroflex and dental affricates in both VOT and voiced periods.

A. VOT Measurement Algorithm

We automatically detected the onset of the plosive release or burst. Pronounced signals were introduced into the filter bank and split to power at each center frequency every 5 ms. The start time of VOT, t1, was determined by comparing powers for adjacent time frames when the number of temporally increasing channels is the maximum. The end of the VOT, t2, was the start point of the formant. Thus, t2-t1 is defined as VOT.

In Section II above, we described the features of correct pronunciation of Chinese aspirated dental and retroflex affricates by observing temporal variation of breathing power spectra during VOT. Powers at each of the 35 channels were checked every 5 ms with 11.025kHz sampling, in accordance with the frequency criteria defined for VOT.

B. Breathing Power Measurement Algorithm

Average power during VOT is defined as follows. Power is deduced every 5ms and are referred to as Pi,j, which means the power at $j \times$ 5ms of the channel i(1-35), where Pi is the integration of the power at each interval for VOT of the channel i, as shown in Equation (1).

$$P_i = \sum_{j=1}^{J} P_{i,j}\left(t_j\right) \quad . \tag{1}$$

Thus the energy, Wi, of the channeli- is defined as

$$W_{i,VOT}=P_i \times 5\ ms. \tag{2}$$

The average power, Pi, av, of each frequency channel during VOT is defined as

$$P_{i,av}=W_{i,VOT}/VOT. \tag{3}$$

Finally, average power, Pvi, av, at channel i in the voiced period, Tvs, can be defined similarly, as

$$Pv_{i,av}=W_{i,vs}/T_{vs}. \tag{4}$$

IV. Automatic Evaluation Procedure

A. Parameters for Discrimination

We extracted the features of correctly pronounced Chinese aspirated dental affricates ca[tsʻa], ci[tsʻi], ce[tsʻɤ], and cu[tsʻu] and aspirated retroflex affricates cha[tʂʻa], chi[tʂʻi], che[tʂʻɤ], and chu[tʂʻu] by observing the spectrum evolution of breathing power during VOT and voiced period of sounds uttered by 40 Chinese native speakers.

TABLE I: Evaluation Criteria on Utterance of Retroflex Aspirated Affricates

Syllable	Channels(CH)	Frequency domain(Hz)	VOT range	Ave.Power in VOT
cha[tʂʻa]	CH15~CH29	2750~5750	0~VOT/2	17 or more
chi[tʂʻi]	CH10~CH32	1750~6350	Whole VOT	25 or more
che[tʂʻɤ]	CH07~CH30	1150~5950	0~VOT*2/3	34 or more
chu[tʂʻu]	CH17~CH31	3250~6150	0~VOT*2/3	11or more

TABLE II: Evaluation Criteria for Formants of Retroflex Affricates during Voiced Period After VOT

Syllable	F1(Hz)/ (CH)	F2(Hz)/ (CH)	F3(Hz)/ (CH)
cha[tʂʻa]	550~750/(CH4)	950~1150/(CH6)	1750~1950/(CH10)
chi[tʂʻi]	150~350/(CH2)	1950~2150/(CH11)	2750~2950/(CH15)
che[tʂʻɤ]	350~550/(CH3)	950~1150/(CH6)	2350~2550/(CH14)
chu[tʂʻu]	150~350/(CH2)	750~950/(CH5)	2750~2950/(CH15)

TABLE III: Evaluation Criteria for Formants of Dental Affricates during Voiced Period After VOT

Syllable	F1(Hz)/ (CH)	F2(Hz)/ (CH)	F3(Hz)/ (CH)
ca[tsʻa]	750~950/(CH5)	1150~1350/(CH7)	2150~2350/(CH12)
ci[tsʻi]	150~350/(CH2)	1350~1550/(CH8)	2550~2750/(CH14)
ce[tsʻɤ]	350~550/(CH3)	1150~1350/(CH7)	2350~2550/(CH13)
cu[tsʻu]	150~350/(CH2)	750~950/(CH5)	2550~2750/(CH14)

Table I and Table II respectively list the evaluation criteria for retroflex aspirated affricates and those in the voiced period after VOT, which depend on the values of F1, F2, and F3. If the power was higher than 17 between 2750 Hz (CH15) and 5750 Hz (CH29) averaged between the beginning of the

VOT and1/2 of VOT, and if high power appears between 550 and 750Hz, 950 and 1150 Hz, and 1750 and 1950 Hz, the utterances are judged to be aspirated retroflex affricate cha[tʂ‘a].

If power is higher than 25between 1750 Hz (CH10) and 6350 Hz (CH32) throughout VOT in Table I, and high power appears between 150 and 350Hz, 1950 and 2150 Hz, and 2750 and 2950 Hz in Table 2, the utterances are judged to be aspirated retroflex affricate chi[tʂ‘i].

If power was higher than 34 at frequencies between 1150 Hz (CH7) and 5950 Hz (CH30) averaged between the beginning of VOT to 2/3 of VOT in Table 1, and high power appears between 350 and 550Hz, 950 and 1150 Hz, and 2350 and 2550 Hz in table 2, the utterances are judged to be aspirated retroflex affricate che[tʂ‘ɤ].

If power is higher than 11 at frequencies between 3250 Hz (CH17) and 6150 Hz (CH31) averaged between the beginning of VOT to 2/3 of VOT in Table I, and high power appears between 150 and 350Hz, 750 and 950 Hz, and 2750 and 2950 Hz in Table II, the utterances were judged to be aspirated retroflex affricate chu[tʂ‘u].

When the distinctive feature does not appear during the VOT period, we refer to Table III, which lists the evaluation criteria for dental aspirated affricates, namely, the values of F1, F2, and F3. If high power appears between 750 and 950Hz, 1150 and 1350 Hz, and 2150 and 2350 Hz, the utterances are judged to be aspirated dental affricate ca[ʦ‘a]. If it appears between 150 and 350 Hz, 1350 and 1550 Hz, and 2550 and 2750 Hz, they are judged to be aspirated dental affricate ci[ʦ‘i]. If it appears between 350 and 550 Hz, 1150 and 1350 Hz, and 2350 and 2550 Hz, they are judged to be aspirated dental affricate ce[ʦ‘ɤ]. Finally, if it appears between 150 Hz and 350 Hz, 750 and 950 Hz, and 2550 and 2750 Hz, they are judged to be aspirated dental affricate cu[ʦ‘u].

B. Automatic Evaluation and Results

We tried to discriminate between the pronunciations of Chinese pairs ca[ʦ‘a] - cha[tʂ‘a], ci[ʦ‘i] - chi[tʂ‘i], ce[ʦ‘ɤ] - che[tʂ‘ɤ], and cu[ʦ‘u] - chu[tʂ‘u] uttered by 50 Japanese students.

Fig. 5 illustrates the flow of our system for the automatic discrimination of these aspirated retroflex and dental affricates pairs. In step 1, the uttered sounds are input to the computer. In step 2, the sounds are automatically analyzed using our 35-channel filter bank to create a data-base of temporal variation of the power spectra. In step 3, VOT is deduced using the algorithm described in subsection III.A.

In step 4, the average power, *Pi*, *av*, is automatically calculated for each channel during VOT, as described in subsection III.B. In step 5, if any distinctive features are found during VOT, the sample is tentatively judged to be aspirated retroflex affricates and differentiated from others by referring to Table I and Table II.

If the utterance fulfills both conditions above, it is successfully identified as one of the four retroflex. Otherwise it is judged not to be a retroflex.

If a sample, judged to be non-retroflex in step 5, fulfills the conditions listed in Table III, it is successfully identified as one of the four aspirated dental affricates. Otherwise it is not judged to be one.

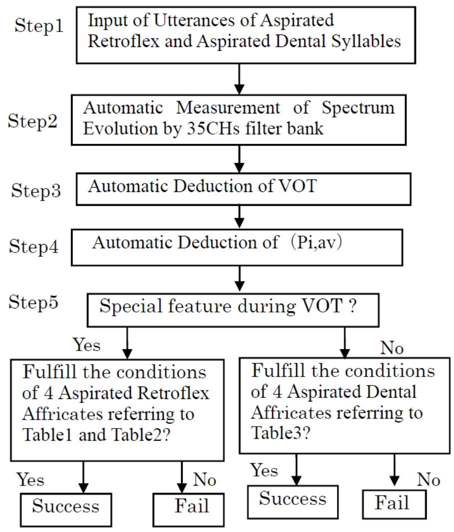

Fig. 5. Discrimination diagram of aspirated retroflex anddental affricate.

TABLE IV: NUMBER OF CORRECTLY JUDGED STUDENT'S PRONUNCIATIONS AMONG 50 ONES BY NATIVE CHINESE SPEAKER AND OUR JUDGMENT SYSTEM

	Aspirated retroflex syllables				Aspirated dental syllables			
	cha[tʂ‘a]	chi[tʂ‘i]	che[tʂ‘ɤ]	chu[tʂ‘u]	ca[ʦ‘a]	ci[ʦ‘i]	ce[ʦ‘ɤ]	cu[ʦ‘u]
Number of correctly judged ones by native Chinese speakers (1)	38	41	32	35	44	42	38	39
Number of correctly judged ones by our judgment system (2)	36	40	30	32	44	40	37	37
Correct judgment ratio (2)/(1)	94%	97%	93%	91%	100%	95%	97%	95%

Table IV lists the numbers of correctly judged utterances out of 50 students' data of aspirated retroflex affricates cha[tʂ‘a], chi[tʂ‘i], che[tʂ‘ɤ] and chu[tʂ‘u] by native Chinese speakers were 38, 41, 32, and 35, respectively. However, those by our judgment system were 36, 40, 30, and 32, respectively.

50 Japanese students were those who had studied Chinese for 3 hours per week for 6 months. They all just followed Standard Chinese or Modern Standard Chinese(Putonghua), the dialects are not contained. All selected 9 native Chinese speakers were raised in Beijing, China. 6 of them are teachers in Chinese for the foreigners at the universities in Beijing. 3 are teachers in Japan. They can speak the exact Standard Chinese(Putonghua). The acceptance or rejection of these data is not affected by dialect pronunciation.

Some of the data which passed the native Chinese screening test were rejected due to its strict discrimination criteria. The ratios of correct judgment by our system and by native Chinese for aspirated retroflex affricates were 94%, 97%, 93% and 91% for cha[tʂ‘a], chi[tʂ‘i], che[tʂ‘ɤ], and chu[tʂ‘u], respectively.

The numbers of correctly judged utterances out of 50 for aspirated dental affricates, ca[ʦ‘a], ci[ʦ‘i], ce[ʦ‘ɤ] and cu[ʦ‘u] by native Chinese speakers were 44, 42, 38, and 39, respectively, and those by our judgment system were 44, 40, 37, and 37, respectively. The ratios of correct judgments by our system to those by native Chinese speakers for aspirated retroflex affricates were 100%, 95%, 97% and 95%, for ca[ʦ‘a], ci[ʦ‘i], ce[ʦ‘ɤ] and cu[ʦ‘u], respectively.

Again, some of the data which passed the screening test by the native Chinese were rejected by our system.

V. Conclusion

We have been studying instruction in the pronunciation of Chinese aspirated sounds, which are generally difficult for Japanese students to perceive and reproduce. We closely examined spectrograms of these sounds uttered by native Chinese speakers and by Japanese students and determined criteria for their correct pronunciations of various aspirated sounds [1-5]. We had previously developed an automatic system for measuring and calculating VOT and the power during VOT of student pronunciations [6], [7].

In this paper, in order to develop the self-learning system of Chinese aspirated dental and retroflex affricates by CAI, we aimed at automatic distinction of the four pairs of aspirated dental and aspirated retroflex affricates ca[ʦ‘a] - cha[tʂ‘a], ci[ʦ‘i] - chi[tʂ‘i], ce[ʦ‘ɤ] - che[tʂ‘ɤ] and cu[ʦ‘u] - chu[tʂ‘u]. We automatically calculated the frequency spectra of these sounds during VOT and voiced periods and extracted the distinctive features of each sound. On that basis, we established criteria for automatically discriminating aspirated retroflex and dental affricates.

Next, we conducted an experiment on the automatic discrimination by our judgment system of50 utterances by Japanese students. The results of the test showed that the system rejected some pronunciations which were judged to be correct by native Chinese speakers. However, the coincidences of the both judgments were 91% to 100% for the four pairs of retroflex and dental affricates.

We plan to apply our system to other samples of speech sounds to improve its performance.

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Akemi Hoshino was born in Shanghai, China on November 1, 1960. She received her Dr. Eng. degree from Tokyo University of marine science and technology of Japan in 2005. She belongs to Toyama national college of technology from 1997 until now.

She is currently an associate professor. “Evaluation of Chinese aspiration sounds uttered by Japanese students using VOT and power (in Japanese), *Acoust. Soc.Jpn.*, vol. 58, no. 11, pp.689-695,(2002).

Her research interests are development of pronunciation training system of Chinese by CAI, and development computer-aided automatic judgment system, and Evaluation of Chinese aspiration sound uttered by Japanese Students based on VOT and power.

Dr. Hoshino is a member of Acoustical Society of Japan and Institute of Electronics, Information, Communication Engineers in Japan.

Akio Yasuda was born in Nagoya, Japan on April 6, 1943. He received MS (1968) and PhD(1975) from Nagoya University. He was a Research associate at Nagoya University in 1972. Since 1975, he joined at Tokyo University of Mercantile Marine as an associate professor.

He was awarded Emeritus Professor at Tokyo University of Marine Science and Technology in 2007.

He is presently majored in Satellite Navigation. Dr. Yasuda is a member of Acoustical Society of Japan, Institute of Electronics, Information, Communication Engineers in Japan, Japan Institute of navigation and Institute of Navigation.