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(54) **METHOD AND APPARATUS FOR
MANDARIN CHINESE SPEECH
RECOGNITION BY USING INITIAL/FINAL
PHONEME SIMILARITY VECTOR**

(52) **U.S. Cl. 704/239**

(57) **ABSTRACT**

(75) **Inventor: Chung-Ho Yang, Towliu City (TW)**

Correspondence Address:
**GREENBLUM & BERNSTEIN
1941 ROLAND CLARKE PLACE
RESTON, VA 20191**

(73) **Assignee: Matsushita Electrical Industrial Co.,
Ltd.**

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Apparatus for Mandarin Chinese speech recognition by using initial/final phoneme similarity vector, for improving the Chinese speech recognition accuracy and downsizing the needed memory is provided. A Mandarin Chinese speech recognition apparatus comprises a speech signal filter for receiving a speech signal and creating a filtered analogue signal, an analogue-to-digital (A/D) converter connected to the speech signal to a digital speech signal, a computer connected to the A/D converter for receiving and processing the digital signal, a pitch frequency detector connected to the computer for detecting characteristics of the pitch frequency of the speech signal thereby recognizing tone in the speech signal, a speech signal pre-processor connected to the computer for detecting the endpoints of syllables of speech signals thereby defining a beginning and ending of a syllable, and a training portion connected to the computer for training an initial part PSV model and a final part PSV model and for training a syllable model based on trained parameters of the initial part PSV model and the final part PSV model.

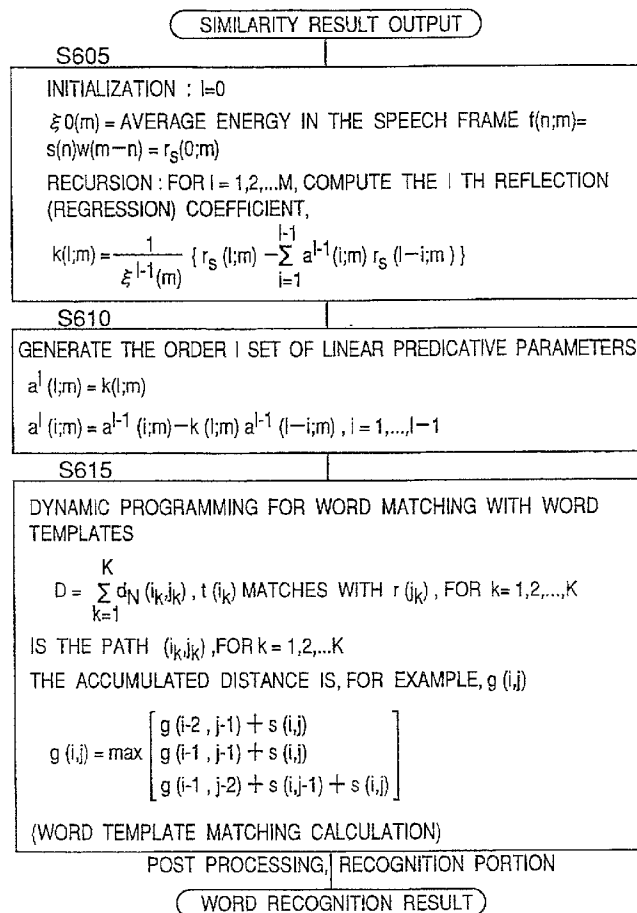


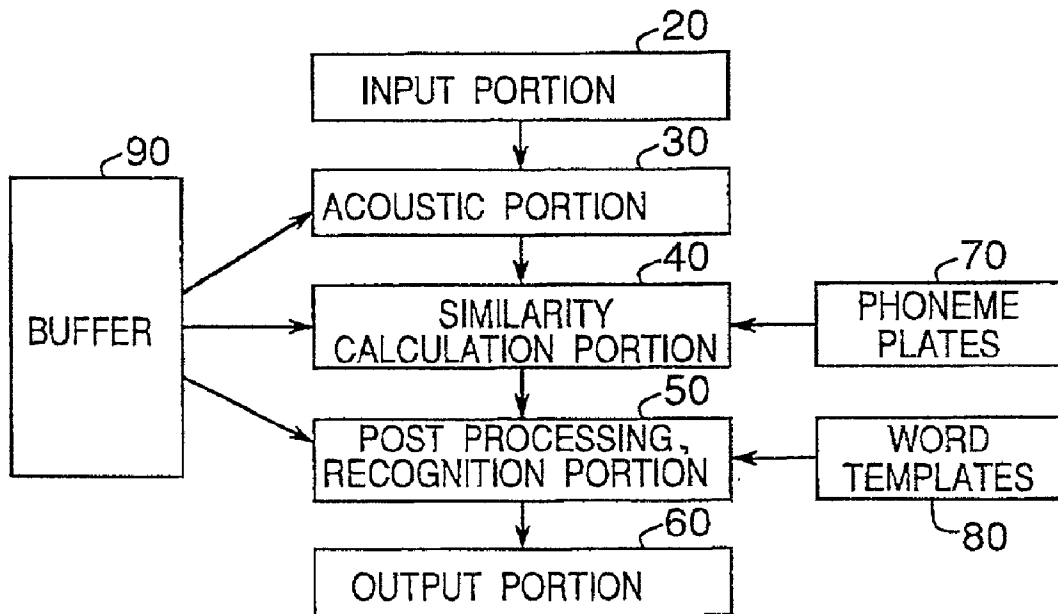
Fig. 1

Fig.2

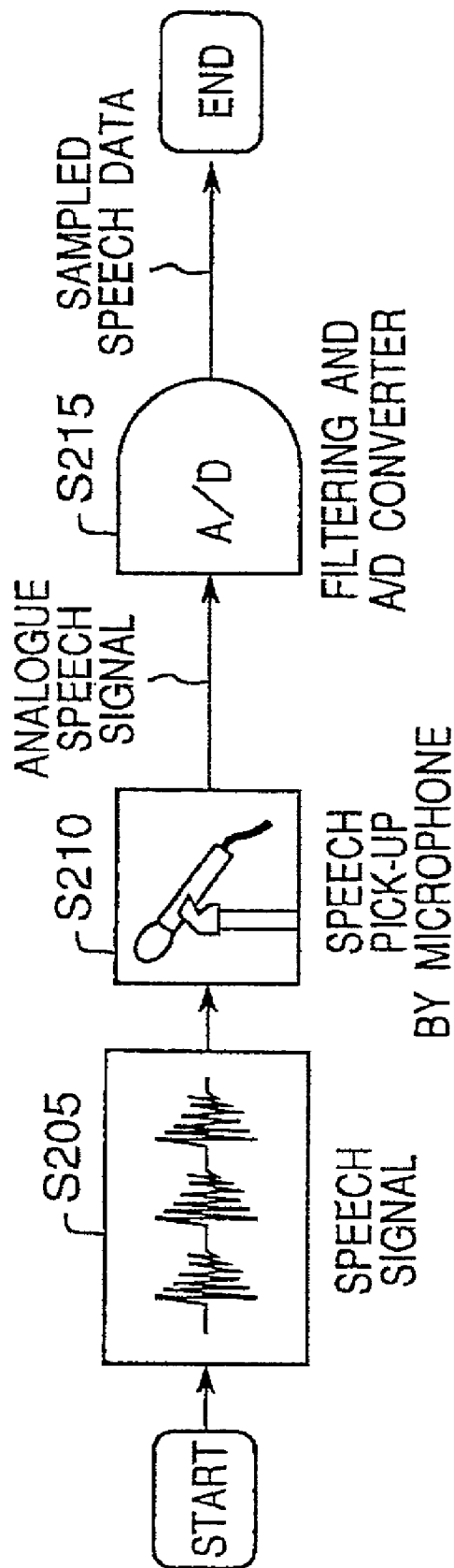


Fig.3

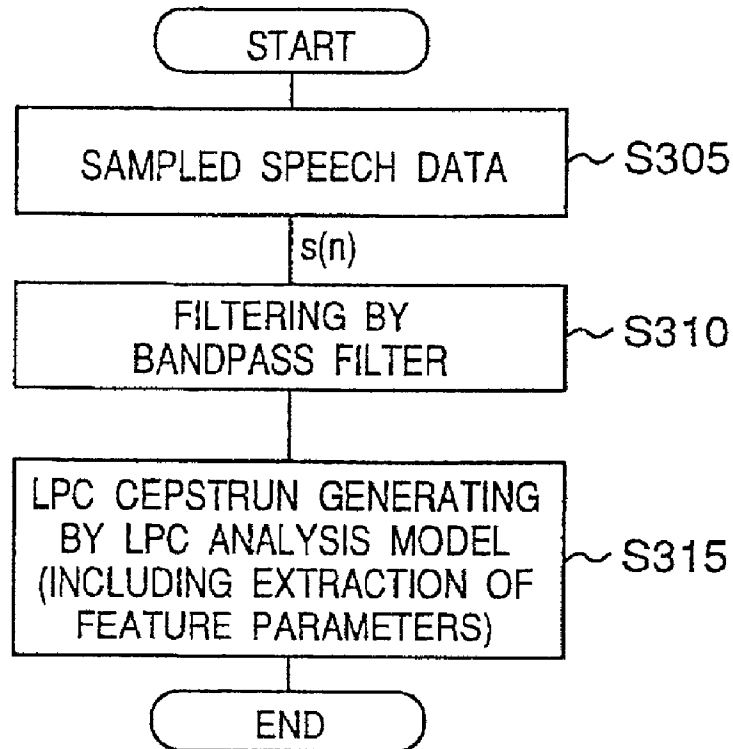


Fig.4

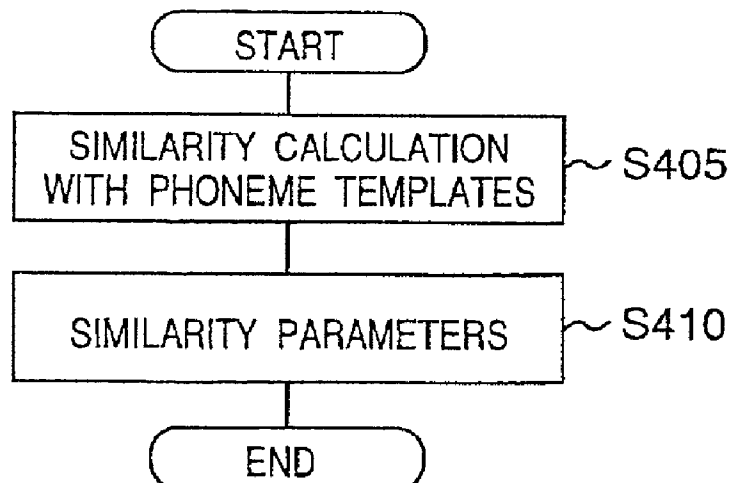


Fig.5

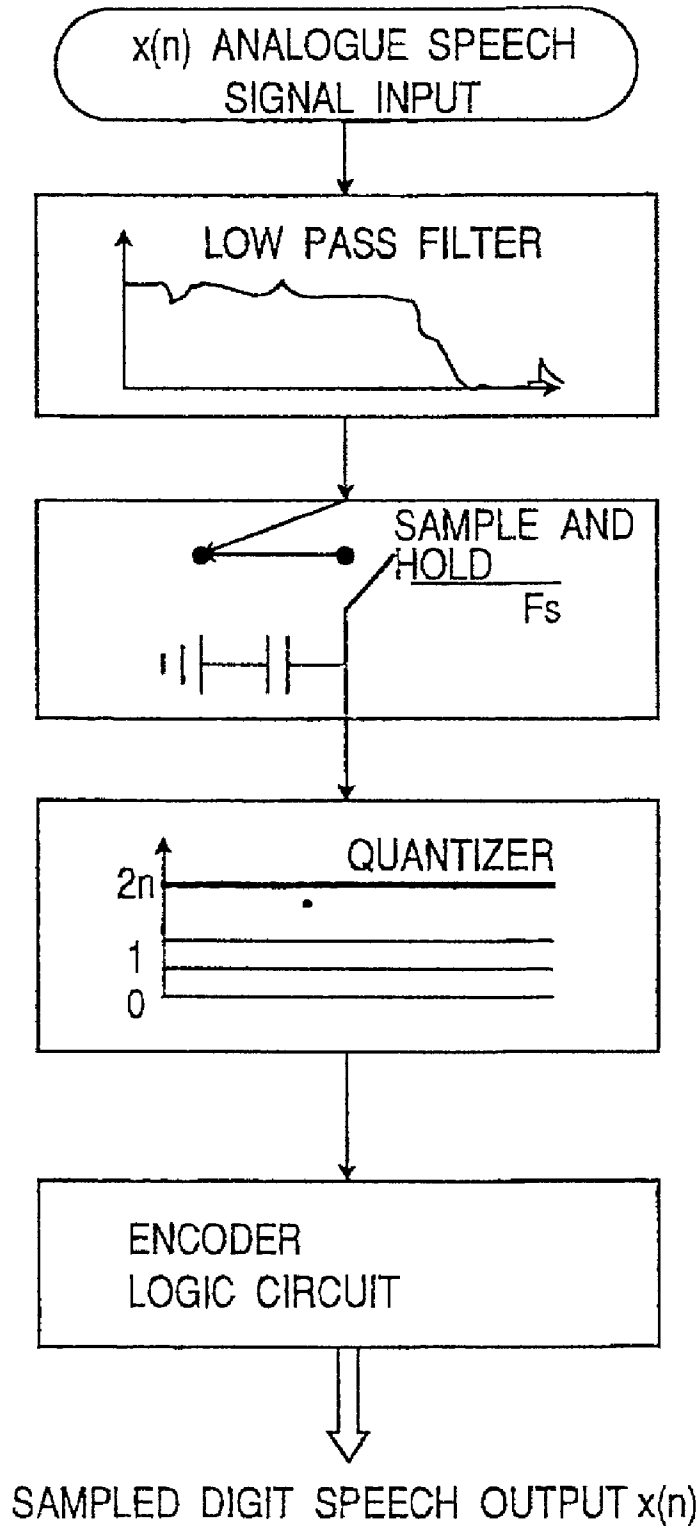


Fig. 6

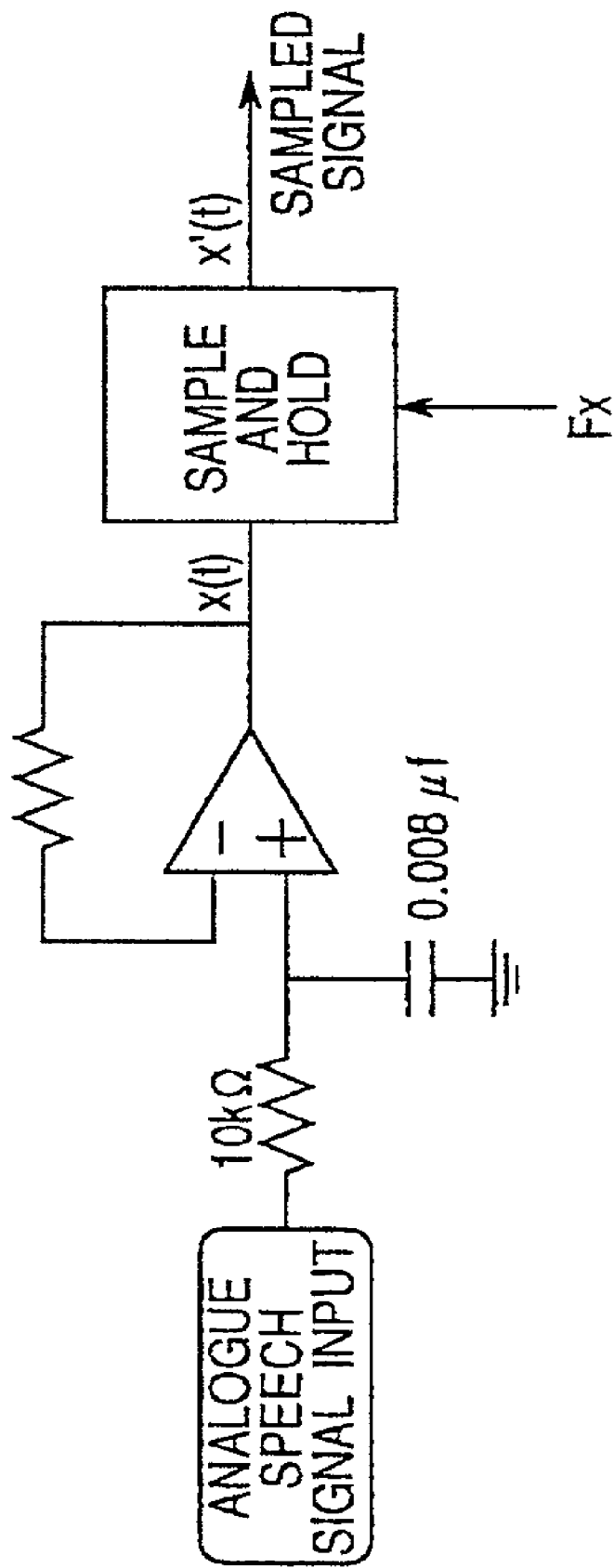


Fig. 7

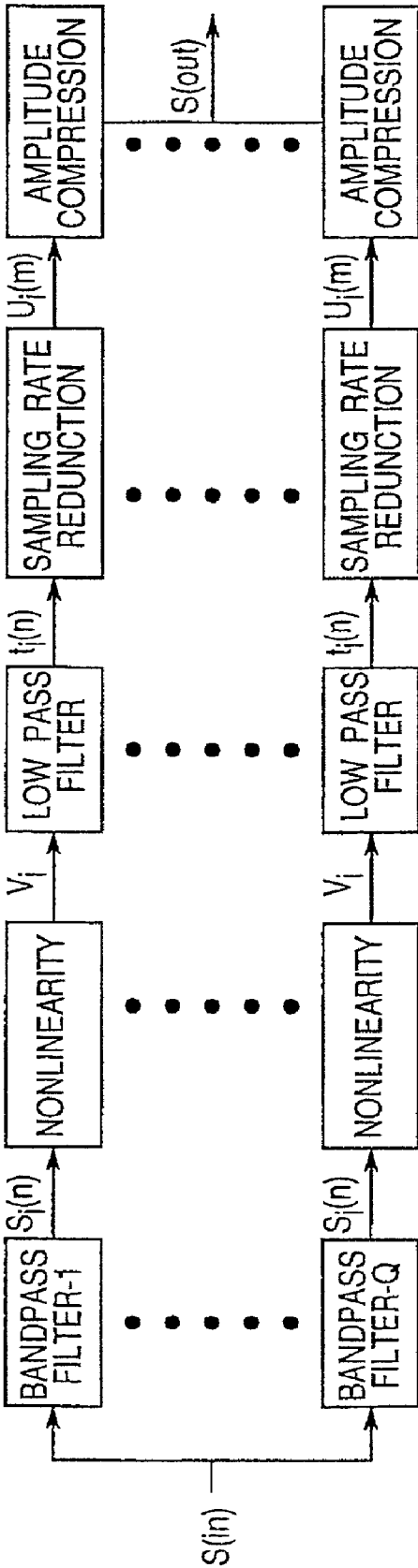


Fig.8

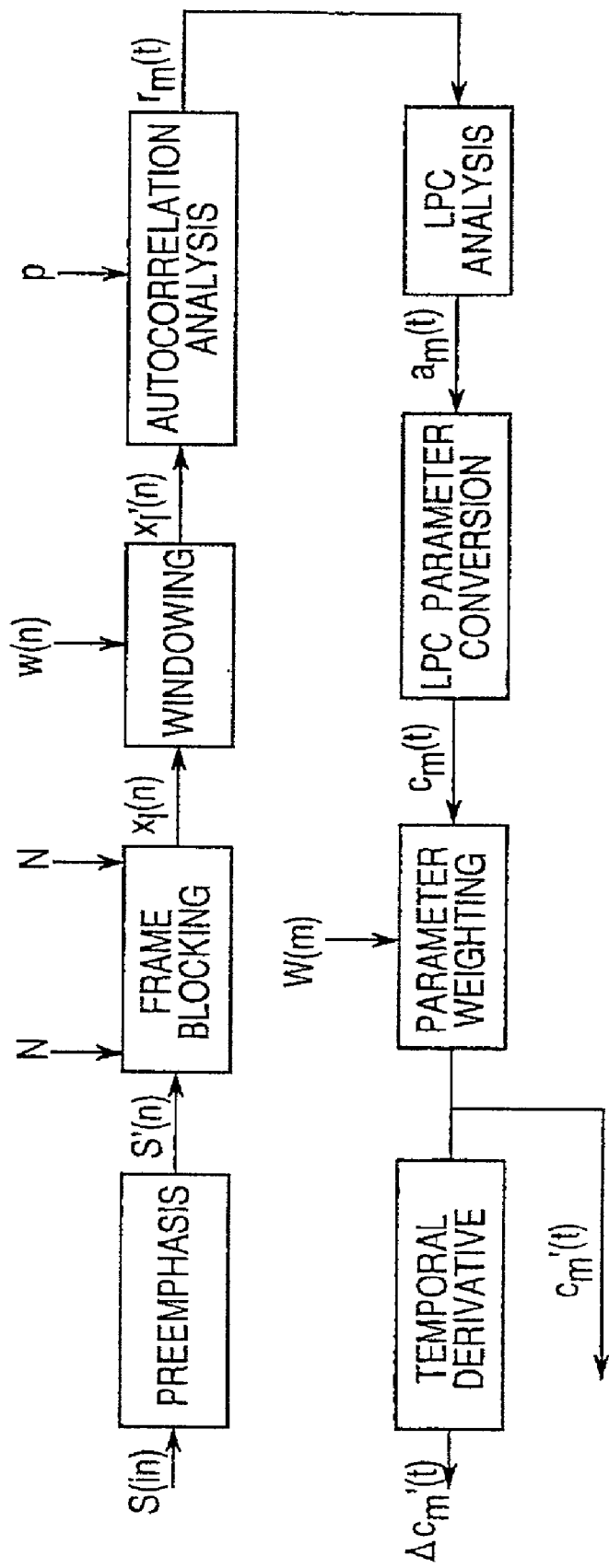


Fig. 9

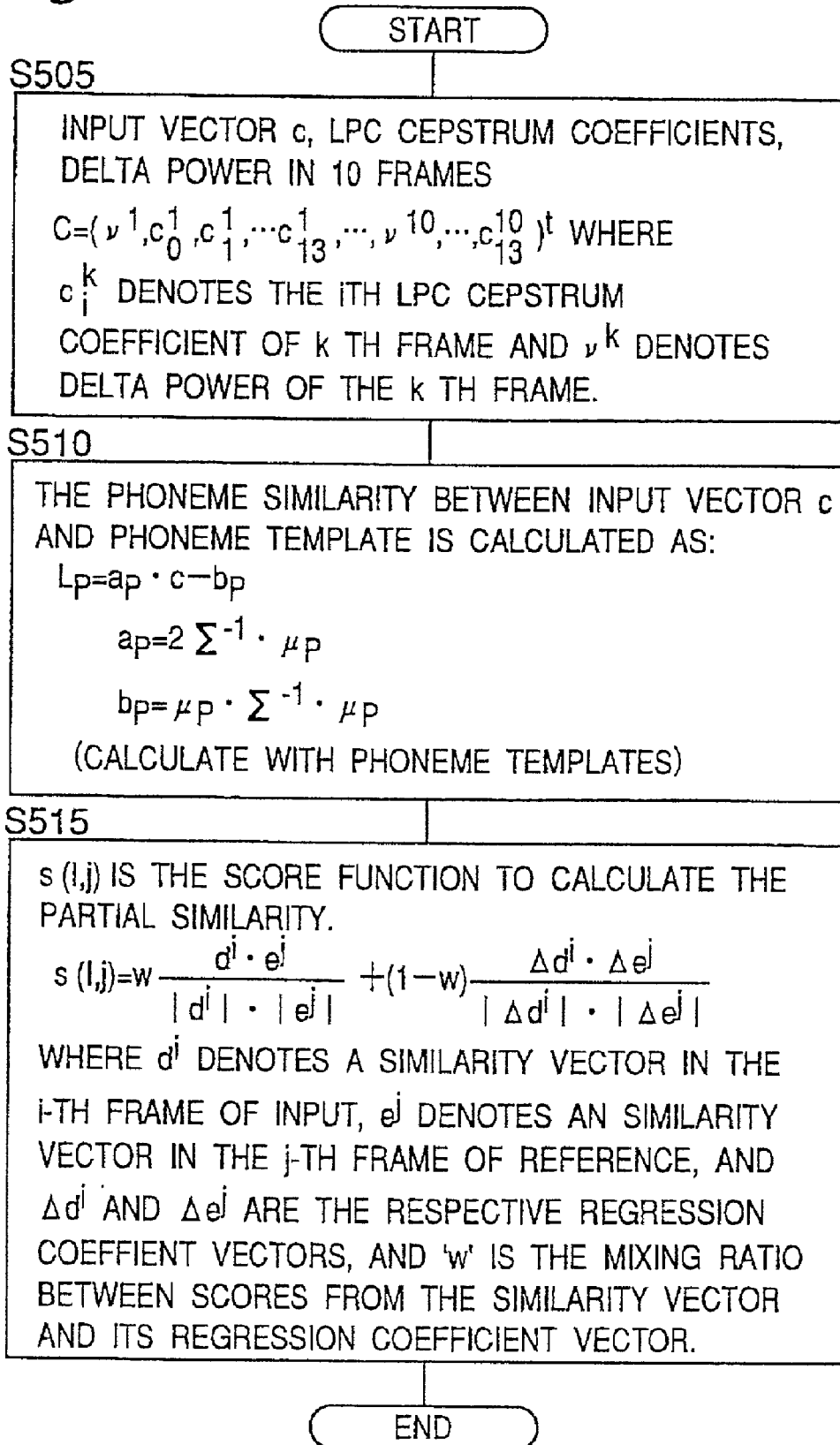


Fig. 10

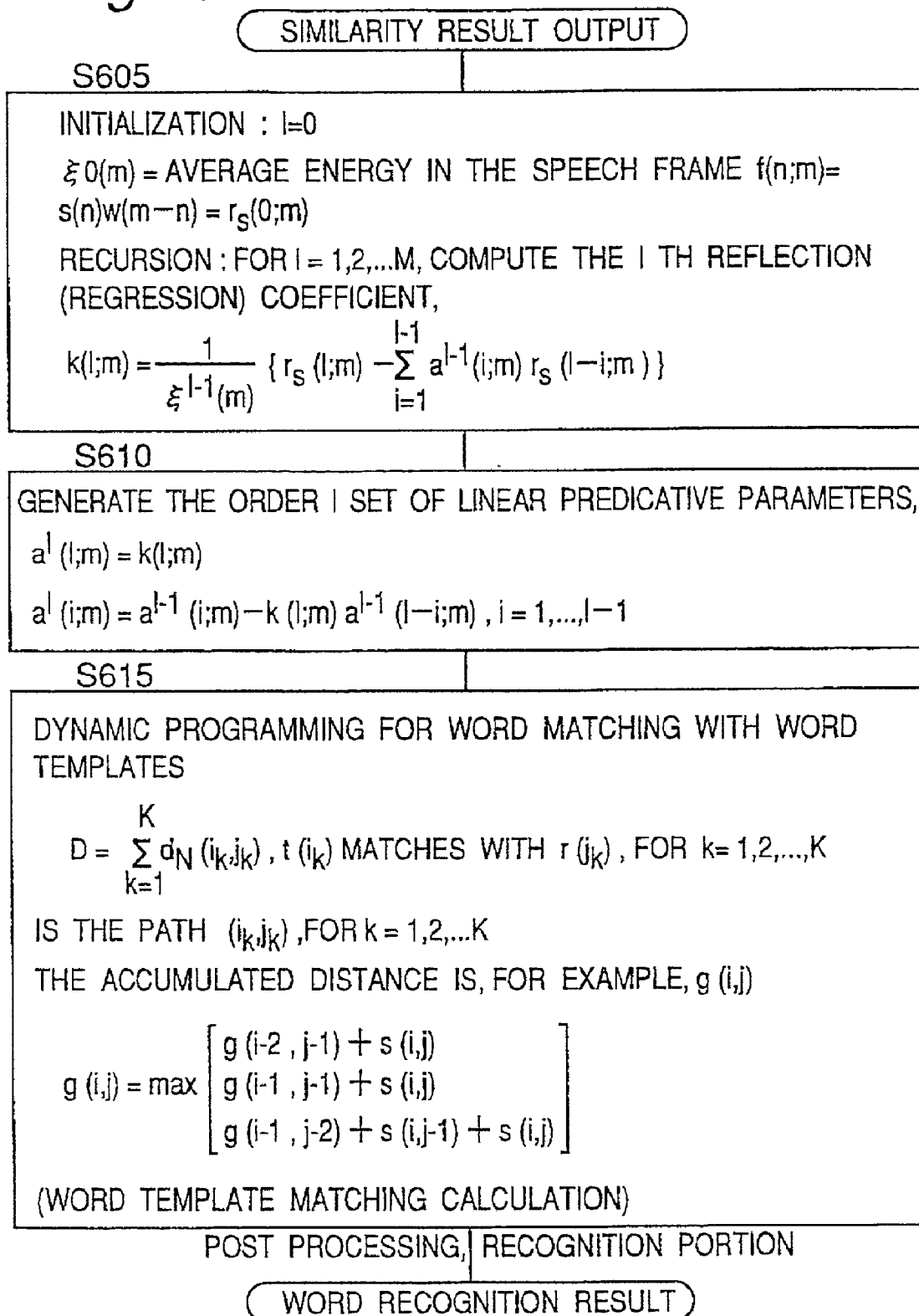


Fig. 11

INITIAL		FINAL		INITIAL-FINAL COMBINATION		TONE	
ㄅ	b	一	i, y	ㄟ	ia	一聲	Space, 1, 6
ㄆ	p	ㄨ	u, w	ㄛ	io	二聲	2, 7
ㄇ	m	ㄩ	iu, yu	ㄜ	ie	三聲	3, 8
ㄏ	f	ㄚ	a	ㄞ	iai	四聲	4, 9
ㄉ	d	ㄛ	o	ㄟ	iau	輕聲	5, 0
ㄊ	t	ㄜ	e	ㄟ	iou		
ㄋ	n	ㄝ	e	ㄟ	ian		
ㄌ	l	ㄞ	ai	ㄟ	in, ien		
ㄍ	g	ㄟ	Ei	ㄟ	iang		
ㄎ	k	ㄠ	Ao	ㄟ	ing, ieng		
ㄏ	h	ㄨ	Ou	ㄨ	ua		
ㄐ	j (i)	ㄜ	An	ㄨ	uo		
ㄑ	ch (i)	ㄟ	En	ㄨ	uai		
ㄒ	sh (i)	ㄠ	Ang	ㄨ	uei		
ㄓ	j	ㄠ	Eng	ㄨ	uan		
ㄔ	ch	ㄟ	Er	ㄨ	uen		
ㄕ	sh			ㄨ	uang		
ㄖ	r			ㄨ	ung, ueng		
ㄗ	tz			ㄩ	iue		
ㄘ	ts			ㄩ	iuai		
ㄙ	s			ㄩ	iun, iuen		
				ㄩ	iung, iueng		

Fig. 12

FINAL INITIAL		NO TRANSITION														
		a	o	e	-i[ʃ]	-i[ʌ]	er	ai	ei	ao	ou	an	en	ang	eng	ong
		a	o	e			er	ai	ei	ao	ou	an	en	ang	eng	
	b	ba	bo					bai	bei	bao		ban	ben	bang	beng	
	p	pa	po					pai	pei	pao	pou	pan	pen	pang	peng	
	m	ma	mo	me				mai	mei	mao	mou	man	men	mang	meng	
	f	fa	fo						fei		fou	fan	fen	fang	feng	
	d	da		de				dai	dei	dao	dou	dan	den	dang	deng	dong
	t	ta		te				tai		tao	tou	tan		tang	teng	tong
	n	na		ne				nai	nei	nao	nou	nan	nen	nang	neng	nong
	l	la		le				lai	lei	lao	lou	lan		lang	leng	long
	g	ga		ge				gai	gei	gao	gou	gan	gen	gang	geng	gong
	k	ka		ke				kai	kei	kao	kou	kan	ken	kang	keng	kong
	h	ha		he				hai	hei	hao	hou	han	hen	hang	heng	hong
	j															
	q															
	x															
	zh	zha		zhe	zhi			zhai	zhei	zhao	zhou	zhan	zhen	zhang	zheng	zhong
	ch	cha		che	chi			chai		chao	chou	chan	chen	chang	cheng	chong
	sh	sha		she	shi			shai	shei	shao	shou	shan	shen	shang	sheng	
	r			re	ri					rao	rou	ran	ren	rang	reng	rong
	z	za		ze		zi		zai	zei	zao	zou	zan	zen	zang	zeng	zong
	c	ca		ce		ci		cai		cao	cou	can	cen	cang	ceng	cong
	s	sa		se		si		sai		sao	sou	san	sen	sang	seng	song

Fig. 13

INITIAL	FINAL									
	i[i]	ia	iao	ie	iou	ian	in	iang	ing	iong
b	yi	ya	yao	ye	you	yan	yin	yang	ying	yong
p	bi		biao	bie		bian	bin		bing	
m	pi		piao	pie		pian	pin		ping	
f	mi		miao	mie	miu	mian	min		ming	
d	di		diao	die	diu	dian			ding	
t	ti		tiao	tie		tian			ting	
n	ni		niao	nie	niu	nian		niang	ning	
l	li	lia	liao	lie	liu	lian		liang	ling	
g										
k										
h										
j	ji	jia	jiao	jie	jiu	jian	jìn	jiang	jing	jiong
q	qi	qia	qiao	qie	qiu	qian	qin	qiang	qing	qiong
x	xi	xia	xiao	xie	xiu	xian	xin	xiang	xing	xiong
zh										
ch										
sh										
r										
z										
c										
s										

Fig. 14

FINAL INITIAL		TRANSITION u										TRANSITION u			
		u	ua	uo	uai	uei	uan	uen	uang	ueng	u	ue	uan	un	
	wu	wa	wo	wai	wei	wan	wen	wang	weng	yu	yue	yuan	yun		
b	bu														
p	pu														
m	mu														
f	fu														
d	du		duo		dui	duan	dun								
t	tu		tuo		tui	tuan	tun								
n	nu		nuo			nuan				nu	nue				
l	lu		luo			luan	lun			lu	lue				
g	gu	gua	guo	guai	gui	guan	gun	guang							
k	ku	kua	kuo	kuai	kui	kuan	kun	kuang							
h	hu	hua	huo	huai	hui	huan	hun	huang							
j										ju	jue	juan	jun		
q										qu	que	quan	qun		
x										xu	xue	xuan	xun		
zh	zhu	zhua	zhuo	zhuai	zhui	zhuai	zhun	zhuang							
ch	chu	chua	chuo	chuai	chui	chuai	chun	chuang							
sh	shu	shua	shuo	shuai	shui	shuai	shun	shuang							
r	ru	rua	ruo		ru	ruan	run								
z	zu		zuo		zui	zuan	zun								
c	cu		cuo		cui	cuan	cun								
s	su		suo		Sui	suan	sun								

Fig. 15

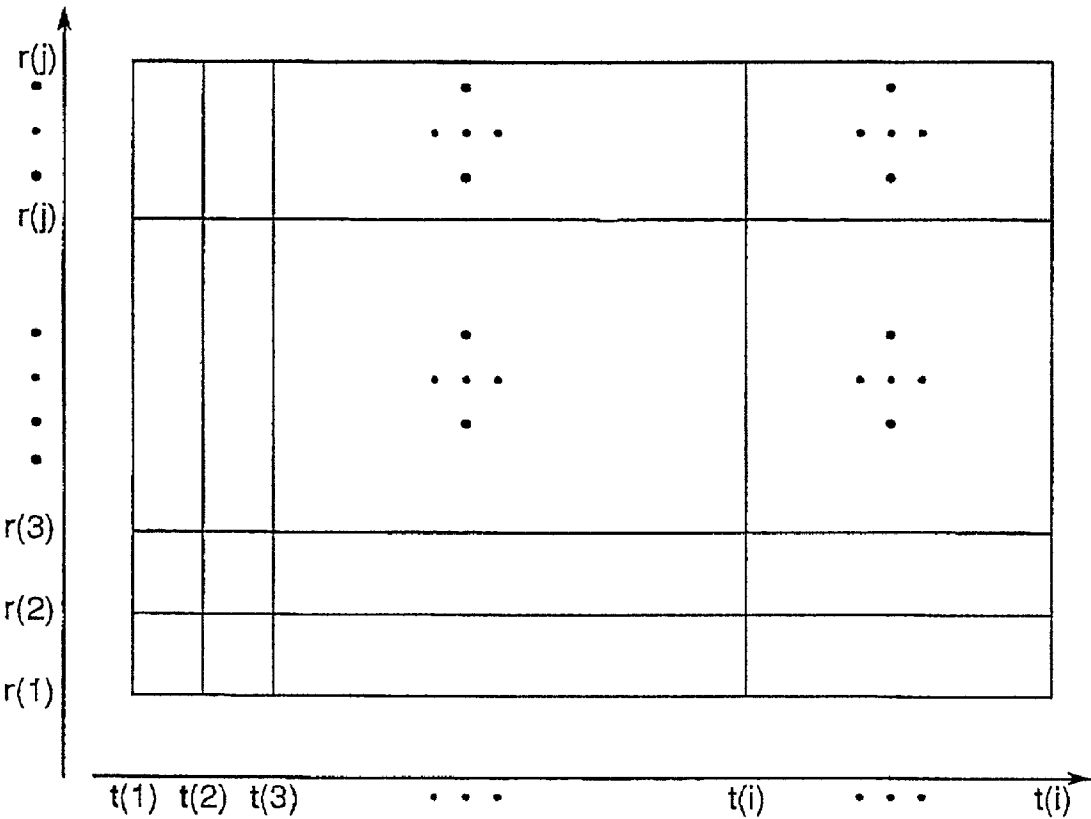


Fig. 16

車站	代碼	車站	代碼	車站	代碼	車站	代碼	車站	代碼	車站	代碼
花東線		北迴線		西幹線		海線				南迴線	
台東	001*	北埔	052	基隆	092*	後龍	121	大林	161	大武	211
新 台東	004*	新城	054	八堵	093*	通霄	125	民雄	162	瀧溪	213
鹿野	008	和平	057	七堵	094	苑里	126	嘉義	163*	金崙	215
瑞源	009	南澳	062*	汐止	096	大甲	128	新營	167*	大 麻 里	217
瑞和	010	東澳	063	南港	097	清水	130	隆田	170	知本	219
關山	012	蘇澳	066	松山	098*	沙鹿	131	善化	172*	康樂	220
池上	015	蘇澳 新	067	台北	100*	山線		新市	173		
富里	018	冬山	069	萬華	101*	苗栗	137*	永康	174		
東竹	020	羅東	070*	板橋	102*	銅鑼	139	台南	175*		
東里	022	宜蘭	073*	樹林	103*	三義	140	大湖	178		
玉里	025*	礁溪	075*	鶯歌	105	后里	143	路竹	179		
瑞德	029	頭城	077*	桃園	106*	豐原	144*	岡山	180*		
富源	031	大溪	080	中壢	108*	台中	146*	楠梓	183*		
光復	034	福隆	083	埔心	109	彰化	149*	左營	184*		
萬營	035	貢寮	084	楊梅	110	員林	151*	高雄	185*		
鳳林	036	雙溪	085*	湖口	112	田中	154*	鳳山	186*		
豐田	040	侯硐	088	新豐	113	二水	155*	九 曲 堂	188		
壽豐	041	瑞芳	089*	竹北	114	林內	156	屏東線			
志學	043			新竹	115*	斗六	158*	屏東	190*		
吉安	045			竹南	118*	斗南	159*	潮州	195		
花蓮	051*							南州	197		
								林邊	199		
								枋寮	203		

METHOD AND APPARATUS FOR MANDARIN CHINESE SPEECH RECOGNITION BY USING INITIAL/FINAL PHONEME SIMILARITY VECTOR

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention related to an apparatus of Chinese recognition by using Initial/Final phoneme similarity vector. The purpose of the invention is to improve recognition accuracy and downsize the demanded memory, which can be built on single DSP (Digital Signal Processing) chip for Mandarin Chinese speech recognition system. More particularly, the invention is focused on a new methodology for not only improving the Chinese speech recognition rate based on Chinese Initial/Final phoneme similarity but also downsizing the needed memory.

[0003] 2. Description of the Prior Art

[0004] From the past more than twenty years, the research and development of Mandarin speech recognition techniques have been very prosperous discussed not only in the academic fields but also in commercialization-oriented private companies. As we can easily understand, human speech is generated according to a shape of vocal tract and its temporal transition. The shape of vocal tract, which depends on the shape or size of the vocal organ, inevitably shows individual differences. On the other hand, the pattern of time sequence of the vocal tract, which also depends on an uttered word that, shows a small individual difference. Therefore, features of utterance should be divided into two factors: the shape of the vocal tract and its temporal pattern. The former shows large difference from speaker to speaker whereas the latter one shows small difference. So if the difference based on the shape of the vocal tract is somehow normalized, the speech of specified speakers can be recognized using only the utterances of a small number of speakers. The difference in the shape of the vocal tracts causes different frequency spectra. One of the methods to normalize the spectral difference among speakers is to classify voice input by matching it with phoneme templates which are made for unspecified speakers. This operation provides similarity, which does not depend very much on the differences among speakers. Meanwhile, the temporal pattern of vocal tract is considered to have small individual difference.

[0005] The motivation for understanding the mechanism of speech production lies in the fact that speech is the human being's primary means of communication. There are areas such as non-linearity of vocal fold vibration, vocal-tract articulator dynamics, knowledge of linguistics rules, and acoustic effects of coupling of the glottal source and vocal tract that continue to be studied. The continued pursuit of basic speech analysis has provided new and more realistic means of performing speech synthesis, coding, and recognition. From the historical progression, one of the first all-electrical networks for modeling speech sounds was developed by J. Q. Stewart (1922). From the ancient system for speech processing to the newest development, we have known speech sounds in terms of the position and movement of the vocal-tract articulators, variation in their time waveform characteristics, and frequency domain properties such as format location and bandwidth. The inability of the speech production system to change instantaneously is due to the requirement of finite movement of the articulators to

produce each sound. Unlike the auditory system, which has evolved solely for the purpose of hearing, organs used in speech production are shared with other functions such as breathing, eating, and smelling. For the purpose of human communication, we shall only be concerned with the acoustic signal produced by talker. In fact, there are many parallels between human and electronic communications. Due to the limitations of the organs for human speech production and the auditory system, typical human speech communication is limited to a bandwidth of 7-8 kHz.

[0006] In the research of vocal tract for computation and science of understanding the relationship between the physical speech signal and the physiological mechanisms, i.e. the human vocal tract mechanism, which produces the speech and the human hearing mechanism, which perceives the speech. That can be named as "acoustics." The newest approach evaluates human speaking and hearing physical systems and, in digitalization, those human communication signals to be parameters, such as acoustical features extraction. The human acoustical features are usually very unique-depends. That is, everyone hold his/her own acoustical features, particularly.

[0007] Usually standard patterns for speaker-independent speech recognition are made by statistically processing speech data of speakers. There are several matching methods: for example, a method using the statistical distances measure, and a method applying the neural net models, such as ROC Pat. No. 303452; and Hidden Markov Model (HMM), such as ROC Pat. No. 283774 and 269036. Especially, numbers of successful HMM are reported using the continuous mixture Gaussian density models. With these methods, spectral parameters are used in speech recognition as a feature parameter and an enormous number of speakers are generally required for training. It also costs very large memory in order to get high recognition rate. If the standard patterns for speaker independent speech recognition can be produced from a small number of speakers, the size of computation will be much smaller than usual. Therefore, human power and computation are saved and speech recognition technique can be easily handled to various applications. For the purpose mentioned above, we proposed our invention of speech recognition apparatus using the similarity vectors as feature parameters. In this method, word templates trained with a small number of speakers yield high recognition rates in speaker-independent recognition. To realize the speech recognition technology in real applications, speech recognizer must be robust to noisy environments and spot intended words from background noise and unintended utterances. Furthermore, speech recognizer must retain high quality performance on portable devices. For these reasons, our invention was focused on small-size programming code but high accuracy rate for portable device which can be built-in a Chinese speech recognition system.

SUMMARY OF THE INVENTION

[0008] There are many algorithms and methodologies have been applied for English speech recognition, however, whereas the Chinese has some crucial properties in its expression of speech, which are very different with Western Languages. The differences, for example, are known as tone information and monosyllable sound pattern for each character of Chinese. In term of the characteristic of Chinese

speech, Chinese spoken language is a bi-syllabic language where one character consists of one consonant or nasal in the front one vowel at the end. The front consonant is called the "Initial" while the ending vowel is called "Final". The Initial has short duration and is affected by the Final while the Final has a transient part in the front. For instance, Chinese characters like: 關 (g+uan1) or 心 (s+ing1) and so on. The middle part of Final is steady and is the same for the whole set of Final group. The ending part of each Final is characterized by an ending consonant whether voiced or unvoiced. Mandarin has a total of 21 Initials and one null Initial and 36 Finals that include middle transient and null Final which compose the whole. If the five tones are not being considered, there are 409 Mandarin syllable sets. Combining tones and phonemes, there are a total number of 1345 different syllables in Mandarin. Another characteristic of Chinese spoken language is Chinese homonyms of which tonal nature where different tones with the same phonemes can represent different characters.

[0009] To get high accuracy recognition rate for Chinese spoken language, the process of extracting relevant information from the Chinese speech signal in an efficient, crucial and robust manner is the key technology. There are many approaches for Chinese speech recognition include the form of spectral analysis used to characterize the time-varying properties of the speech signal as well as various types of signal pre-processing and post-processing to make the speech signal robustly to the recording environment. They are usually connecting to Digital Signal Processing (DSP) skill and many mathematical models and formulae, such as DFT (or FFT), FIR, z-transform, LPC, neural network and Hidden Markov Model. Though such many sorts of mathematical models have been submitted to apply in Chinese speech recognition, it seems that those methods still can not improve recognition accuracy well from a small number of trained speaker database.

[0010] In the basic conventional Initial-Final structural based approach for Chinese speech recognition, it uses the Initial-Final characteristic of Chinese spoken language. This conventional approach uses this method to model input syllable as a concatenation of Initial and Final. However, using this approach does not imply that the input syllable will be segmented into two parts explicitly. Using such Initial-Final structure modeling, the whole set of syllables must be recognized by identifying Initials and Finals. For systems employing Initial-Final characteristics, recognition of initials and finals is the vital part. In the early stage, several authors, such as that disclosed in ROC Pat. No. 273615, 278174 (U.S. Pat. No. 5,704,004) and 219993 proposed methodologies in separate recognition of Initials and Finals. U.S. Pat. No. 5,704,004 is the counterpart of ROC Pat. 278174. A syllable is first segmented in two parts and recognized separately. That is, the Initial is first segmented from the syllable and classified into voiced and unvoiced by extracting features like zero-crossing rate, average energy and syllable duration. Then, a feature code-book can be set up by using these feature vectors. Recognition can be done by finite-state vector quantization. In those conventional systems, the final is known in advance. Therefore, consonant classification can be done within the recognized Final group. The recognition accuracy of this conventional approach is merely up to 93% (ROC Pat. No. 273615) according to empirical result. Meanwhile, those

approaches have to build a large speech corpus from numerous speakers for its processing.

[0011] Therefore, we propose our invention to improve not only in recognition rate but also our apparatus of Chinese speech recognition system that can reduce the size of the programming code. This invention is for developing a high accuracy speaker-independent Chinese speech recognition system using the similarity vectors as feature parameters. An empirical result of word recognition rate is 97.5% with 106 cities cover Taiwan based on noisy environment. Our invention of accuracy rate in Chinese speech recognition has much higher than conventional methods (such as ROC Pat. No. 273615, 278174). We have got more 4.5% higher than any other traditional methods.

[0012] The object of this invention is to provide apparatus for Mandarin Chinese speech recognition by using initial/final phoneme similarity vector, for improving the Chinese speech recognition accuracy and downsizing the needed memory.

[0013] The object of this invention is also to provide the method of Mandarin Chinese speech recognition by using initial/final phoneme similarity vector.

[0014] A Mandarin Chinese speech recognition method comprises the step of training a Phoneme Similarity Vector (PSV) model on the initial part to create an initial part model having trained initial part model parameters, the step of training a PSV on the final part to create a final part model having trained final part model parameter, the step of training a PSV on the training speech syllable to create a syllable model using the trained initial part parameter values and the trained final part parameter values as starting parameters for the syllable model, the step of operating on an object speech sample with the syllable model, the step of recognizing the object speech sample as an object speech syllable based on a degree of match of the object speech sample to the syllable model, and the step of representing the object speech sample as a Chinese character in accordance with the object speech syllable.

[0015] A Mandarin Chinese speech recognition method as in claim 1 further comprises the step of training a Dynamic Time Warping (DTW) on a sequence of Chinese characters as used in context to create a Chinese language model, the step of operating on a sequence of object speech syllables in the object speech sample with the Chinese language model, the step of representing the object speech sample as a Chinese character sequence in accordance with a match of the sequence of object speech syllables to the Chinese language model, and the step of representing the object speech sample as a Chinese character sequence in accordance with a sequence of matches to the object speech syllables.

[0016] A Mandarin Chinese speech recognition apparatus comprises, a speech signal filter for receiving a speech signal and creating a filtered analogue signal, an analogue-to-digital (A/D) converter connected to the speech signal to a digital speech signal, a computer connected to the A/D converter for receiving and processing the digital signal, a pitch frequency detector connected to the computer for detecting characteristics of the pitch frequency of the speech signal thereby recognizing tone in the speech signal, a speech signal pre-processor connected to the computer for

detecting the endpoints of syllables of speech signals thereby defining a beginning and ending of a syllable, and a training portion connected to the computer for training an initial part PSV model and a final part PSV model and for training a syllable model based on trained parameters of the initial part PSV model and the final part PSV model.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] These and other objects and features of the present invention will become clear from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings throughout which like parts are designated by like reference numerals, and in which:

[0018] FIG. 1 shows a system block diagram of a preferred embodiment in the present invention;

[0019] FIG. 2 shows a schematic diagram illustrating the processing procedure of INPUT PORTION of the present invention;

[0020] FIG. 3 shows a schematic diagram illustrating the processing procedure of ACOUSTIC ANALYSIS PORTION of the present invention;

[0021] FIG. 4 shows a schematic diagram illustrating the processing procedure of SIMILARITY CALCULATION PORTION of the present invention;

[0022] FIG. 5 shows a detailed processing diagram illustrating the filtering and Analogue to Digital Signal converting of the present invention;

[0023] FIG. 6 shows an electronic circuit diagram of Analogue to Digital converting of the present invention;

[0024] FIG. 7 shows a detailed processing diagram illustrating the BANDPASS filter of the present invention;

[0025] FIG. 8 shows a detailed processing diagram illustrating the LPC analysis block of the present invention;

[0026] FIG. 9 shows a processing procedure and its algorithms illustrating the similarity calculation and similarity parameter generation of the present invention;

[0027] FIG. 10 shows a processing procedure of the RECOGNITION PORTION of the present invention;

[0028] FIG. 11 shows a table illustrating the Chinese basic syllable and tone information for phoneme modeling of the present invention;

[0029] FIGS. 12, 13 and 14 show tables illustrating the Chinese detailed phoneme information for phoneme modeling of the present invention;

[0030] FIG. 15 shows a table illustrating the dynamic programming of the present invention; and

[0031] FIG. 16 shows the 106 city names for empirical word templates.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0032] The present invention overcomes the deficiency and limitations of the prior art with a system and method for recognizing Mandarin Chinese speech with small number of training speakers. There are five portions in our speech

recognition apparatus, including INPUT PORTION 20, ACOUSTIC ANALYSIS PORTION 30, SIMILARITY CALCULATION PORTION 40, RECOGNITION PORTION 50, and OUTPUT PORTION 60. The present invention advantageously implements in a size-intensive device when determining the Initial and Final of a syllable to identify the phonetic information of a Chinese word. Referring now to FIG. 1, the architecture of our invention for Chinese speech recognition is illustrated. In our apparatus, INPUT PORTION 20 deals the human speech signal input. Referring now to FIG. 2, a basic block diagram of INPUT PORTION 20 is shown. Because human speech is a kind of analogue signal, the signal from microphone input have to be converted into digital signals in order to further computation by computer (S205 and S210). In general, the frequency of human speech is on the range of 125 Hz~3.5 KHz, so a low pass filter has to be built in front of A/D converter to get real human speech signal and filter out the redundant noise signal from real environment (S215).

[0033] Referring now to FIG. 3, a basic block diagram of ACOUSTIC ANALYSIS PORTION 30 is shown. In this acoustic analysis portion 30, there are three specific processing blocks (S305, S310 and S315), including band-pass filter, extraction of feature parameter and LPC analysis model.

[0034] After the acoustic analysis portion 30 is calculated, referring now to FIG. 4, the block diagram illustrates the SIMILARITY CALCULATION PORTION 40.

[0035] Our apparatus begins with a user creating a speech signal to accomplish a given task. In the second step, the spoken output is first recognized in that the speech signal is decoded into a series of phonemes that are meaningful according to the phoneme templates. The acoustic analysis portion 30 analyses speech inputs and the extracted LPC (Linear Predictive Coding) cepstrum coefficients and delta power. The extracted parameters are matched with many kinds of phoneme templates, and static phoneme similarity and the first order regression coefficients of phoneme similarity are calculated in the similarity calculation portion 40. After that, the time sequence of those number of phoneme templates to define a dimensional similarity coefficient vectors and regression coefficient vectors can be obtained. In the similarity calculation portion 40, mahalanobis' distance algorithm is employed for distance measure, where covariance matrixes for all of the phonemes are assumed to be the same. The meaning of the recognized words is obtained by the post processor that uses a dynamic programming to match inputted word with the real word and the word having been previously recognized by phoneme similarity calculation. Consequently, the post processing make a decision according to the previous phoneme result that reduces the complexity of all the recognition model. Finally, the recognition system responds to the user in the form of a voice output, or equivalently, in the form of the requested action being performed, with the user being prompted for more input.

[0036] The follows, we are going to explicate detailed processing of our apparatus not only in the explicit of the each procedure but also the algorithm will be described. FIG. 5 illustrates the processing procedure that explicates how the analogue to digital signal converting works. Most signals in nature are in analogue form, necessitating an

analogue-to-digital conversion process, which involve the following steps. 1) The analogue input signal. This signal is continuous in both time and amplitude. 2) The sampled signal. This signal is continuous in amplitude but defined only at discrete points in time. 3) The digital signal, $x(n)$ ($n=0, 1, \dots$) This signal exists only at discrete points in time and at each time point can only have one of 2^B values. Referring now to **FIG. 6**, the electronic circuit of A/D converter can be presented.

[0037] **FIG. 7** illustrates the detailed processing steps of band-pass filter of the ACOUSTIC ANALYSIS PORTION. The sampled speech signal, $s(n)$, is passed through a bank of Q band-pass filters, giving the signals

$$S_i(n) = s(n) * h_i(n), \quad 1 \leq i \leq Q$$

$$= \sum_{m=0}^{M_i-1} h_i(m)s(n-m)$$

[0038] where we have assumed that the impulse response of the i^{th} band-pass filter is $h_i(m)$ with a duration of M_i samples. Meanwhile, assume that the output of the i^{th} band-pass filter is a pure sinusoid at frequency w_i , that is, $S_i = \alpha_i \sin(w_i n)$. If we use a full-wave rectifier as the non-linearity, that is,

$$\begin{aligned} f(S_i(n)) &= S_i(n) \text{ for } S_i(n) \geq 0 \\ &= -S_i(n) \text{ for } S_i(n) < 0 \end{aligned}$$

[0039] then we can represent the nonlinearity output as

$$V_i(n) = f(S_i(n)) = S_i(n) \cdot W(n)$$

[0040] where $W(n) = +1$ if $S_i(n) \geq 0$

[0041] $= -1$ if $S_i(n) < 0$

[0042] After the nonlinearity processing, the role of the low-pass filter is to filter out the higher frequency. Although the spectrum of the low-pass signal is not a pure DC impulse, the instead the information in the signal is contained in a low-frequency band around DC. Thus an important role of the final low-pass filter is to eliminate the undesired spectral peaks. In the sampling rate reduction step, the low-pass filtered signals, $t_i(n)$, are resampled at a rate on the order of 40-60 Hz, and the signal dynamic range is compressed using an amplitude compression scheme. At the output of the analyzer, if we use a sampling rate of 50 Hz and we use a 7 bit logarithmic amplitude compressor, we get an information rate of 16 channels times 50 (samples per second per channel) times 7 (bits per sample), or 5600 (bits per second). Thus, for this simple example, we have achieved about a 40-to-1 reduction in bit rate.

[0043] The LPC analysis model of the ACOUSTIC ANALYSIS PORTION is illustrated in **FIG. 8**. The LPC method has been used in a large number of recognizers for a long time. In particular, the basic idea behind the LPC model is that a given speech sample at time n , $S(n)$, in the preemphasis box, can be approximated as a linear combination of the past p speech samples, such that

$$S'(n) = \alpha_1 S(n-1) + \alpha_2 S(n-2) + \dots + \alpha_p S(n-p)$$

[0044] where the coefficients $\alpha_1, \alpha_2, \dots, \alpha_p$ are assumed constant over the speech analysis frame. In our apparatus, we define the value $\alpha_1, \alpha_2, \dots, \alpha_p$ as 0.95. In the step of

the Frame Blocking, the previously dealing of the pre-emphasized speech signal, $S'(n)$, is blocked into frames of N samples, with adjacent frames being separated by M samples. Assume we denote the l^{th} frame of speech by $x_l(n)$, and there are L frames within the entire speech signal, then

$$x_l(n) = S'(Ml+n), \quad n=0, 1, \dots, N-1, \quad l=0, 1, \dots, L-1$$

[0045] In our apparatus, the values for N and M are 300 and 100, the values corresponding to the sampling rate of the speech are 8kHz. After that, the next step in the processing is to window each individual frame so as to minimize the signal discontinuities at the beginning and end of each frame. In our system, we define the window as $w(n)$, $0 \leq n \leq N-1$, and then the result of windowing is the signal

$$x'_l = x_l(n)w(n), \quad 0 \leq n \leq N-1.$$

[0046] The window in our apparatus used for the autocorrelation method of LPC is the Hamming window, which has the form

$$w(n) = 0.54 - 0.46 \cos\left(\frac{2\pi n}{N-1}\right), \quad 0 \leq n \leq N-1$$

[0047] Following, an autocorrelation analysis should be processed. Each frame of windowed signal is next autocorrelated to give

$$r_l(m) = \sum_{n=0}^{N-1-m} x'_l(n)x'_l(n+m), \quad m=0, 1, \dots, p$$

[0048] where the highest autocorrelation value, p , is the order of the LPC analysis. The next processing stage is the LPC analysis, which converts each frame of $p+1$ autocorrelations into an "LPC parameter set," in which the set might be the LPC coefficients, the reflection coefficients, the log area ratio coefficients, and the cepstral coefficients. In our system, we use Durbin's method and can formally be given as the following algorithm:

$$E^{(0)} = r(0)$$

$$k_i = \left\{ r(i) - \sum_{j=1}^{i-1} \alpha_j^{(i-1)} r(i-j) \right\} / E^{(i-1)}, \quad 1 \leq i \leq p$$

$$\alpha_i^{(i)} = k_i$$

$$\alpha_j^{(i)} = \alpha_j^{(i-1)} - k_i \alpha_{i-j}^{(i-1)}$$

$$E^{(i)} = (1 - k_i^2) E^{(i-1)}$$

[0049] The set of equations above can be calculated recursively for $i=1, 2, \dots, p$, and the final solution is given as $\alpha_m = \text{LPC coefficients} = \alpha_m^{(p)}, 1 \leq m \leq p$.

[0050] After having obtained the LPC analysis coefficients have been done, LPC Parameter is converted to Cepstral Coefficients whose processing is going to be dealt. This very important LPC parameter set, which can be derived directly from the LPC coefficient set, is the LPC cepstral coefficients, c_m . The recursion used is:

$$C_0 = \ln \delta^2$$

$$C_m = a_m \sum_{k=1}^{m-1} \left(\frac{k}{m} \right) C_K a_{m-k}, 1 \leq m \leq p$$

$$C_m = \sum_{k=1}^{m-1} (k/m) C_K a_{m-k}, m > p$$

[0051] Where δ^2 is the gain term in the LPC model. So until the description above, we have got the input vector C composed of LPC cepstrum coefficients and delta power in many frames.

[0052] FIG. 9 illustrates the detailed processing steps and algorithms for the similarity calculation portion of our apparatus. In this similarity calculation portion, we employ the simplified Mahalanobis's distance for distance measure, where covariance matrixes for all the phonemes are assumed to be identical. Input vector c is composed of LPC cepstrum coefficients, delta power in 10 frames. As the first box of FIG. 9 mentioned, the input vector c is expressed as:

$$c = (v^1, c_0^1, c_1^1, \dots, v^{10}, \dots, c_{13}^{10})^T$$

[0053] where c_i^k denotes the i-th LPC cepstrum coefficient of the k-th frame and v^k denotes delta power of the k-th frame.

[0054] The phoneme similarity between input vector c and phoneme template (phoneme p) is calculated as

$$L_p = a_p \cdot c - b_p$$

$$a_p = 2 \sum^{-1} \cdot \mu_p$$

$$b_p = \mu_p \cdot \sum^{-1} \cdot \mu_p$$

[0055] where μ_p is a mean vector of phoneme p, and Σ is the covariance matrix.

[0056] After the static phoneme similarities are obtained, regression coefficients of the phoneme similarities are computed using static phoneme similarities over 50 msec. The word templates are produced by concatenating sub-word units such as CV and VC obtained from a few speakers' speech. Especially, in the similarity calculation portion, it includes phoneme-templates that consist of a Chinese Initial field and a Chinese Final one. For Chinese syllables that have both an Initial and a Final, an Initial field stores a textual representation of the Initial and a Final field stores a textual representation of the Final. There are 409 kinds of sub-word units. Basic Chinese phonetic symbol can be found in FIG. 11, FIG. 12, FIG. 13, and FIG. 14. According, the similarity parameter can be obtained by the calculation of $s(i, j)$, which is the score function to calculate the partial similarity (s515).

$$s(i, j) = w \frac{d^i \cdot e^j}{|d^i| \cdot |e^j|} + (1 - w) \frac{\Delta d^i \cdot \Delta e^j}{|\Delta d^i| \cdot |\Delta e^j|}$$

[0057] where d^i denotes a similarity vector in the i-th frame of input, e^j denotes a similarity vector in the j-th frame of reference, and Δd^i and Δe^j are the respective regression coefficient vectors, and 'w' is the mixing ratio between scores from the similarity vector and its regression coefficient vector. The trajectories of the similarity are regression coefficients are averaged for each sub-word unit and stored in a sub-word dictionary. The main invention of our apparatus is that when speech pattern input into the microphone, the time sequences of similarity vector and regression coefficients vector for each frame are calculated as feature parameters.

[0058] Referring now to FIG. 10, the RECOGNITION PORTION is shown. These time sequences of the feature parameters of input speech and reference in the dictionary are compared with Dynamic Programming (DP) matching and the most similar word is selected as a recognition results. In this portion, we employ the most widely used technology that is well known as "Dynamic time Warping (DTW)" for our word template recognition processing. DTW is fundamentally a feature-matching scheme that inherently accomplishes "time alignment" of the sets of reference and test features through a DP procedure. By time alignment we mean the process by which temporal regions of the test utterance are matched with appropriate regions of the reference utterance. The need for time alignment arises not only because different utterances of the same word will generally be of different duration, but also because phonemes within words will also be of different duration across utterances. In the third box of FIG. 10, that is, in S615 the Dynamic Programming for word matching with word templates algorithms are shown as:

$$D = \sum_{k=1}^K d_N(i_k, j_k),$$

[0059] $t(i_k)$ matches with $r(j_k)$,

[0060] for $k=1, 2, \dots, K$

[0061] is the path (i_k, j_k) , for $k=1, 2, \dots, K$

[0062] the accumulated distance is, for example, $g(i, j)$

$$g(i, j) = \max \begin{bmatrix} g(i-2, j-1) + s(i, j) \\ g(i-1, j-1) + s(i, j) \\ g(i-1, j-2) + s(i, j-1) + s(i, j) \end{bmatrix}$$

[0063] FIG. 15 illustrates the test and reference feature vectors associated with the i and j coordinates of the search grid, respectively.

[0064] Chinese phoneme templates of our apparatus for Chinese speech recognition are trained by 212 word sets spoken by 20 speakers. 10 male and 10 female. They are made from time-spectral patterns around distinctive frames as epoch frame. For example, the epoch frames of vowels are in the middle of duration and those of unvoiced consonant are at the end of duration.

[0065] In the empirical result, based on 106 city names cover Taiwan of FIG. 16, the table as following shows the

accuracy of traditional LPC cepstrum coefficient recognition rate.

Precision of Feature Parameters	32 bit	8 bit	6 bit	4 bit
LPC Cepstrum Coefficients Recognition Rate (%)	84.3	74.1	65.0	64.9

[0066] On the other hand, based on the same experimental data of FIG. 16, the empirical result of our invention below shows our apparatus in accuracy rate has been much improved by our algorithm.

Precision of Feature Parameters	32 bit	8 bit	6 bit	4 bit
Similarity Vector Recognition Rate (%)	97.5	97.5	97.5	97.3

[0067] It is clearly known that, according to these two tables above, recognition rate of our invention is much higher than traditional one. Moreover, our apparatus can get higher accuracy rate even though the extracted parameters are from 4 bits sampling. In almost all traditional approaches, the parameter extraction is used on 32 bits (4 bytes) for feature representation. In our apparatus, however, the parameter can merely be extracted by 4 bits and get high precision.

[0068] Although the present invention has been fully described in connection with the preferred embodiment thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications are apparent to those skilled in the art. Such changes and modifications are to be understood as included within the scope of the present invention as defined by the appended claims unless they depart therefrom.

What is claimed is:

- 1. A Mandarin Chinese speech recognition method comprising the step of:
 - training a Phoneme Similarity Vector (PSV) model on the initial part to create an initial part model having trained initial part model parameters;
 - training a PSV on the final part to create a final part model having trained final part model parameter;
 - training a PSV on the training speech syllable to create a syllable model using the trained initial part parameter

- values and the trained final part parameter values as starting parameters for the syllable model;
 - operating on an object speech sample with the syllable model;
 - recognizing the object speech sample as an object speech syllable based on a degree of match of the object speech sample to the syllable model; and
 - representing the object speech sample as a Chinese character in accordance with the object speech syllable.
2. A Mandarin Chinese speech recognition method as in claim 1 further comprising the step of:
- training a Dynamic Time Warping (DTW) on a sequence of Chinese characters as used in context to create a Chinese language model;
 - operating on a sequence of object speech syllables in the object speech sample with the Chinese language model;
 - representing the object speech sample as a Chinese character sequence in accordance with a match of the sequence of object speech syllables to the Chinese language model; and
 - representing the object speech sample as a Chinese character sequence in accordance with a sequence of matches to the object speech syllables.
3. A Mandarin Chinese speech recognition apparatus comprising:
- a speech signal filter for receiving a speech signal and creating a filtered analogue signal;
 - an analogue-to-digital (A/D) converter connected to the speech signal to a digital speech signal;
 - a computer connected to the A/D converter for receiving and processing the digital signal;
 - a pitch frequency detector connected to the computer for detecting characteristics of the pitch frequency of the speech signal thereby recognizing tone in the speech signal;
 - a speech signal pre-processor connected to the computer for detecting the endpoints of syllables of speech signals thereby defining a beginning and ending of a syllable; and
 - a training portion connected to the computer for training an initial part PSV model and a final part PSV model and for training a syllable model based on trained parameters of the initial part PSV model and the final part PSV model.

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