Development of Parameters for Diagnosing Laryngeal Diseases*

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ABSTRACT

Many people suffer from various laryngeal diseases. Since we can notice voice change easily, acoustic analysis can be helpful to diagnose the diseases. Several attempts have been made to clarify the relation between the parameters and the state of sick vocal folds but any decisive parameters are not found yet. The purpose of this study was to select and develop those parameters useful for diagnosing and differentiating laryngeal diseases. We examined eight MDVP parameters, and two additional MFCC and LPC parameters obtained from the production of an open vowel by 252 subjects with or without laryngeal diseases. Using a statistical procedure through the artificial neural networks, we attempted to differentiate laryngeal disease groups. Results showed that the LPC parameters indicated the highest differentiating rate by the networks followed by the MFCC and the MDVP parameters. In addition, Jita, Shim and NHR among the MDVP parameters came out better parameters in diagnosing laryngeal diseases.

Keywords: Differential Diagnosis, Voice Recognition, MFCC, LPC, MDVP

1. Introduction

Laryngeal diseases cause voice changes at an early stage. An early diagnosis of laryngeal cancer will be helpful to improve the quality of a potential patient's life as well as enhancing his or her survival rate. Moreover, the voice can be used effectively for remote examination, treatment and group checkups, because they are non-invasive, simple and prompt. In order to diagnose laryngeal diseases from a voice signal, it is essential to develop acoustic parameters which provide sufficient information on the

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physiological state of the larynx. Many researchers have attempted and reported on some acoustic parameters in this regard.

Several researchers (Yanagihara 1967;Yumoto et al. 1982; Kasuya et al. 1986) reported that the characteristics of laryngeal diseases could be identified effectively using the noise components from the pathological voices. Iwata et al. (1970) also suggested that the parameters relating to phonation quotients are important to the differential diagnosis of laryngeal diseases while Iwata (1972) proposed that the parameters relating to pitch fluctuation are important to the differential diagnosis of laryngeal diseases.

In addition to the development of these specific parameters, studies have been conducted to differentiate and diagnose laryngeal diseases by combining several parameters. Koike et al. (1977) used the basic frequency and the vibration of voice intensity for specific laryngeal diseases. Horii et al. (1980) conducted a study using Jitt and Shim. Mashima et al. (1987) reported the findings of a study using APQ, PPQ and voice noise. Koizumi et al. (1995) conducted a study to find effective parameters using an analysis and synthesis method to estimate the characteristics of vocal cord nodules. Alwan et al. (1995) conducted a study on the parameters using a time and frequency composition method to measure the degree of voice disorder. Ciocea et al. (1997) used formant-to-area mapping to differentiate and diagnose voice disorder. Recently Wang et al. (1999) attempted to diagnose laryngeal cancer using a cumulative frequency curve using 33 parameters that were created by analyzing the voices recorded in a soundproof room using the MDVP. Jo et al. (1999) developed new parameters using cepstrum, conducted collective selection examinations and reported selection rates of higher than 80 percent.

However, those efforts thus far have yet defined clearly the relation between acoustic parameters and the various characteristics of laryngeal diseases. In this regard, this study aimed to select and develop those parameters that are useful for the differential diagnosis of laryngeal diseases. To this end, eight parameters were selected from the major parameters from the MDVP (multi-dimensional voice program) of the CSL (computerized speech lab, Kay Elemetrics Co.). The authors also included two additional parameters: MFCC (mel-frequency cepstrum coefficient) which reflects human auditory characteristics, and LPC (linear predictive coefficient) which indicates characteristics of the vocal tract. MFCC and LPC parameters are commonly used in voice recognition techniques and considered to be robust against noise levels. Moreover, the artificial neural networks were used as the classifier for laryngeal diseases. The procedure is considered as excellent in generalizing voice signals with much variation. Unlike consecutive methods, the networks can conduct a parallel analysis owing to their structural characteristics as well and they can efficiently handle a large amount of data at one time. Using those parameters in artificial neural networks, we will examine which

parameters work better in the differentiation and diagnosis of laryngeal diseases.

2. Subjects and Methods

2.1 Data collection

Voice data were collected from three groups: two groups with malignant or benign diseases and a normal control group. Table 1 shows their distribution. 41 patients in the malignant group had squamous cell carcinoma in a laryngeal tissue examination. Benign group included 192 patients who complained about hoarseness. The subjects of the normal control group were 19 male or females without any laryngeal complaints.

Table 1. Distribution of diseases

Disease distributions	No. of patients (persons)
cancer	41
polyp	90
palsy	23
Reineke's Edema	31
nodule	48
normal	19
Total	252

2.2 Recording and voice analysis

Each subject produced the vowel /a:/ for about two to three seconds continuously in a comfortable level 15 cm away from a microphone in a soundproof room. The recording was made on a DAT at a sampling rate of 48 kHz and a 16 bit quantization level. Then, the data were input to a computer on which eight parameters of STD, Jita, Shim, vFo, vAm, NHR, VTI and SPI (see Table 2) were obtained using Kay's Multi-Dimensional Voice Program.

Table 2. MDVP 8 parameters used in this study

Parameters		Reference values	Unit
Jita	Absolute Jitter	83.2	us
NHR	Noise-to-Harmonic Ratio	0.19	
Shim	Shimmer percent	3.81	%
SPI	Soft Phonation Index	14.12	
STD	Standard Deviation of the Fundamental Frequency		Hz
vAm	Peak Amplitude Variation	8.20	%
vFo	Fundamental Frequency Variation	1.1	%
VTI	Voice Turbulence Index	0.061	

Matlab 5.3 (Mathwork, Inc.) was used to determine such voice recognition parameters as MFCC and LPC from the voice data. The order was usually assigned in proportion to the sampling rate, but we set the order at 13, and 28, respectively by means of an heuristic method (Figures 1 and 2). The size of each analysis frame was set at 20 ms while that of frame movement, at 10 ms.

Figure. 1. MFCC extraction process

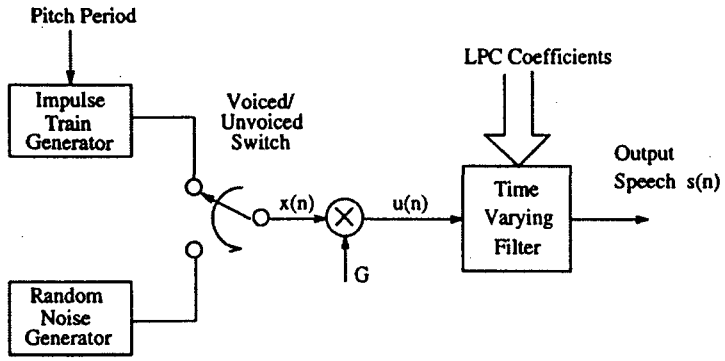

Figure. 2. Block-diagram of LPC model.

2.3 Statistical analysis

The average values, standard deviations and statistical significance of the eight parameters for the various laryngeal diseases were obtained (Table 3). Then a one-way variate analysis method was employed using Microcal Origin 5.0. The statistically significant difference between each pair of normal controls and five disease groups (cancer, edema, nodule, polyp and palsy) was tapped on the eight MDVP parameters and on the LPC and MFCC parameters. Then, 10 comparison groups were formed by pairing two disease groups each (cancer-edema, cancer-nodule, cancer-palsy, cancer-polyp, edema-nodule, edema-palsy, edema-polyp, nodule-palsy, nodule-polyp and palsy-polyp). The analysis was conducted at a reliability of 95% and a significance level of 0.05 (Tables 4, 5 and 6).

2.4 Classification test of diseases using multilayer perceptron artificial neural network

Specific parameter values for various laryngeal diseases including the eight MDVP parameters and the MFCC and LPC parameters were entered into artificial neural networks and the networks were trained with an error back-propagation method. Finally

a system was created to automatically classify diseases by the threshold values learned.

The artificial neural networks used in this study had a multilayer perceptron structure including an input layer, a concealment layer and an output layer. The input layer consisted of various neurons: two neurons for the MDVP parameters and 13 neurons for the MFCC parameters or 28 neurons for the LPC parameters. The output layer consisted of two neurons for the classification results. The concealment layer consisted of five neurons that worked by an heuristic method. The experiment was conducted with the initial learning rate set at 0.01, the maximum learning iterations were set at 40,000 and the learning arrival error was set at 0.01. The number of subjects in each disease group varied greatly. Thus, some data in the same disease group were copied and added to fill the gap between the groups in comparison. 2/3 of the total data were used for learning while the remainder, for testing.

3. Results and Discussion

Table 3 shows the average values and their standard deviations including statistical significance. Generally, the group with malignant laryngeal diseases showed higher results in STD, Jita, NHR, Shim, SPI, vAm and vFo than the group with benign laryngeal diseases. Individual variation seems high. A one-way ANOVA was conducted for the normal control group against the disease groups. All the parameters showed significant differences at $p<0.05$.

Table 3. Values of each parameter in 5 laryngeal diseases

para-meters	laryngeal diseases						
	cancer	edema	nodule	palsy	polyp	normal	p value
STD(Hz)	21.83±15.43	8.13±11.13	4.58±3.75	8.60±10.53	8.63±14.05	2.41±1.68	< 0.001
Jita(us)	335.32±88.96	230.46±174.67	49.67±41.85	157.62±171.88	84.49±127.03	54.49±31.65	< 0.001
NHR	0.58±021	0.34±0.14	0.16±0.08	0.22±0.13	0.16±0.11	0.14±0.04	< 0.001
Shim(%)	17.50±4.45	13.69±7.14	5.83±3.93	10.51±5.97	7.71±3.77	3.65±1.59	< 0.001
SPI	10.99±3.96	8.46±4.64	7.73±3.83	8.85±6.84	5.21±2.41	8.71±4.70	< 0.001
vAm(%)	31.05±10.86	22.54±10.91	18.62±9.98	20.60±8.21	18.98±8.43	12.12±4.80	< 0.001
vFo(%)	16.95±6.73	6.35±8.30	2.19±1.90	5.05±6.98	4.47±8.08	1.66±0.78	< 0.001
VTI	0.06±0.03	0.09±0.04	0.06±0.02	0.07±0.02	0.07±0.03	0.05±0.02	< 0.001

Jita, NHR, Shim, STD, vAm, vFo and VTI showed significant differences for the normal group against the disease groups. Jita, NHR, Shim, SPI, STD, vAm and vFo showed significant differences for the benign group against the malignant one.

For the malignant group, Jita, NHR, Shim, SPI, STD, vAm and vFo appeared significant differences for vocal cord nodules. Jita, NHR, Shim, SPI, STD, vAm and vFo showed significant differences for vocal cord polyps. Jita, NHR, STD, vAm, vFo and VTI showed significant differences for Reinke edemas. Jita, NHR, Shim, STD, vAm and vFo showed significant differences for vocal cord paralysis.

For the benign group, Jita, NHR, Shim, vFo and VTI came out significant for Reinke edemas and vocal cord nodules. Jita, NHR, Shim, and SPI were significant for Reinke edemas and vocal cord polyps. Only NHR showed significant for Reinke edemas and vocal cord paralysis. Jita and Shim showed significant differences for vocal cord nodules and vocal cord paralysis, respectively. Only SPI showed significant differences for vocal cord nodules and vocal cord polyps. Shim and SPI showed significant differences for vocal cord paralyses and vocal cord polyps.

The one-way ANOVA tests on the group with normal control, the group with malignant laryngeal diseases and the group with benign laryngeal diseases showed that Jita, NHR and Shim were significant parameters. The results of the analysis of all the 10 comparative groups indicated that Jita, NHR and Shim was significant for the seven groups (Table 4).

STD shows the scope of the change in voice pitches. vAm and vFo indicate the scope of the change in voice amplitude and fundamental frequency, respectively. Therefore, the parameter values change to a great extent depending upon the emotional state of the speaker. Thus, it is thought that STD, vFo, vAm have nothing to do with disease characteristics. The parameters that are most advantageous in differentiating and diagnosing laryngeal diseases are Jita, Shim and NHR. Jita and Shim indicate that sequential cycle-to-cycle frequency and amplitude variations in sustained vowel phonation have significant meaning to the differential diagnosis of laryngeal diseases. NHR reflects vowel irregularity as it is an index that indicates the rate of abnormal harmonics in the range between 1500 Hz and 4500 Hz in the harmonics energy of the frequency band between 70 Hz and 4500 Hz. This means that there is a close relationship with changes in pitch. As each case may differ, the quality of the voice with benign laryngeal diseases deteriorates in the order of vocal cord nodule, vocal cord polyp, Reinke edema and vocal cord paralysis. The results obtained from the MDVP parameters showed the same order as above. In addition, it was difficult to differentiate between vocal cord nodules and vocal cord polyps. The rates of differential diagnosis for these two diseases were 83.3 percent and 53.3 percent respectively, which are relatively low rates. However, the rate of a differential diagnosis for benign or malignant laryngeal diseases showed favorable results.

Table 4. Results of signigicant MDVP parameters for classification

comparison			Jita	NHR	Shim	SPI	STD	vAm	vFo	VTI
cancer	vs	edema	o	o			o	o	o	o
cancer	vs	nodule	o	o	o	o	o	o	o	
cancer	vs	palsy	o	o	o		o	o	o	
cancer	vs	polyp	o	o	o	o	o	o	o	
edema	vs	nodule	o	o	o				o	o
edema	vs	palsy		o						
edema	vs	polyp	o	o	o	o				
nodule	vs	palsy	o		o					
nodule	vs	polyp				o				
palsy	vs	polyp			o	o				
normal	vs	abnormal	o	o	o		o	o	o	o
benign	vs	malignant	o	o	o	o	o	o	o	

Using the MFCC and LPC parameters, the one-way ANOVA test was performed for the normal control group against the disease groups. As a result, most of the MFCC and LPC coefficients were significant for all the comparative disease groups (Tables 5 and 6).

Table 5. Results of signigicant MFCC parameters for classification

comparison			MFCC(mel-frequency cepstrum coefficient)												
			1	2	3	4	5	6	7	8	9	10	11	12	13
cancer	vs	edema	o	o		o	o	o	o	o		o	o		o
cancer	vs	nodule	o	o		o	o	o	o	o	o	o	o	o	o
cancer	vs	palsy	o	o	o	o	o	o	o	o	o	o	o		o
cancer	vs	polyp	o	o		o	o	o	o	o		o	o		o
edema	vs	nodule	o	o	o	o	o	o	o	o	o	o	o	o	o
edema	vs	palsy	o	o	o	o	o	o	o	o	o	o	o		o
edema	vs	polyp	o	o	o	o	o	o	o	o	o	o	o		o
nodule	vs	palsy	o	o	o	o	o	o	o		o	o			o
nodule	vs	polyp	o	o	o	o	o	o	o		o	o	o		o
palsy	vs	polyp	o	o	o	o	o	o	o		o	o	o		o
normal	vs	abnormal	o	o		o	o			o	o				o
benign	vs	malignant		o							o				o

Table 6. Results of signigicant LPC parameters for classification

comparison			LPC (linear predictive coefficient)													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
cancer	vs	edema	o	o	o	o	o	o					o		o	o
cancer	vs	nodule	o	o	o	o	o	o	o				o			o
cancer	vs	palsy	o	o	o	o	o	o		o	o	o	o	o		o
cancer	vs	polyp	o	o	o	o	o	o					o			o
edema	vs	nodule	o	o	o	o	o	o					o			o
edema	vs	palsy	o	o	o	o	o			o				o		o
edema	vs	polyp	o	o	o	o	o	o					o			o
nodule	vs	palsy	o	o	o	o		o		o				o		o
nodule	vs	polyp	o	o	o	o		o	o			o	o			o
palsy	vs	polyp	o	o	o	o				o				o		o
normal	vs	abnormal	o	o	o	o						o				o
benign	vs	malignant		o	o	o	o	o								

comparison			LPC (linear predictive coefficient)													
			15	16	17	18	19	20	21	22	23	24	25	26	27	28
cancer	vs	edema	o	o	o	o	o	o	o		o	o	o	o	o	o
cancer	vs	nodule	o	o	o	o	o	o		o	o	o	o	o	o	o
cancer	vs	palsy	o	o	o	o	o	o				o	o	o		
cancer	vs	polyp	o	o	o	o	o	o				o	o	o		
edema	vs	nodule	o	o	o			o	o	o	o	o	o	o	o	o
edema	vs	palsy	o	o	o			o	o		o	o	o	o	o	o
edema	vs	polyp	o	o	o			o	o		o	o	o	o	o	o
nodule	vs	palsy	o	o					o	o	o		o			
nodule	vs	polyp	o	o					o	o	o		o	o		
palsy	vs	polyp	o	o								o	o			
normal	vs	abnormal	o	o	o		o						o	o		o
benign	vs	malignant	o	o	o	o	o	o								

The MDVP, MFCC and LPC parameters were entered into the artificial neural networks and the laryngeal diseases were differentiated and diagnosed. The results of the differential diagnosis using the MDVP parameters showed that the possibility of differentiating and diagnosing normal as normal was 89.5 percent and the possibility of differentiating and diagnosing laryngeal diseases as such was 87.6 percent. The possibility of differentiating and diagnosing benign diseases as benign was 100 percent while that of differentiating and diagnosing malignant laryngeal diseases as malignant was 89.1 percent. Of the 11 comparative groups, the differential diagnosis of cancer-nodule and cancer-polyp showed the highest rate and the differential diagnosis of

palsy-polyp showed the lowest rate.

Using the MFCC parameters, the possibility of differentiating and diagnosing normal as normal and laryngeal diseases as such came out 89.9 percent and 73.6 percent, respectively. The possibility of differentiating and diagnosing benign laryngeal diseases as benign and malignant laryngeal diseases as malignant were 100 percent and 94.1 percent, respectively. Of the 11 comparative groups, the differential diagnosis of cancer-nodule indicated the highest rate and the differential diagnosis of cancer-polyp and palsy-polyp appeared the lowest rate.

Using the LPC parameters, the possibility of differentiating and diagnosing normal as normal and laryngeal diseases as such turned out to be both 100 percents. The possibility of differentiating and diagnosing benign diseases as benign and malignant as such were 100 percent and 94.1 percent, respectively. Of 11 comparative groups, the differential diagnosis of cancer-edema and cancer-polyp showed the highest rate and the differential diagnosis of the nodule-polyp group indicated the lowest rate. When using the LPC parameters, the groups of cancer-edema, cancer-palsy, cancer-polyp, edema-nodule, edema-palsy, edema-polyp, nodule-palsy, nodule-polyp and palsy-polyp showed the highest rates of differential diagnosis with the artificial neural networks. The group of cancer-nodule showed the highest rate in the cases of both the MFCC parameters and the MDVP parameters. The group with normal-abnormal and benign-malignant showed the highest rate in the cases of both the MFCC parameters and the MDVP parameters (Table 7).

Table 7. Comparison of classification rate in MDVP, MFCC and LPC parameters (%)

Comparison groups	MDVP			MFCC			LPC		
	Sensitivity		Specifi-city	Sensitivity		Specifi-city	Sensitivity		Specifi-city
cancer-edema	100	83.3	91.6	80.0	76.6	78.3	100	100	100
cancer-nodule	100	93.3	96.6	100	93.3	96.6	90.0	100	95.0
cancer-palsy	100	70.0	85.0	93.3	80.0	86.6	93.3	86.6	90.0
cancer-polyp	100	93.3	96.6	50.0	93.3	71.6	100	100	100
edema-nodule	90.0	93.3	91.6	93.3	93.3	93.3	93.3	100	96.6
edema-palsy	90.0	63.3	76.6	93.3	93.3	93.3	100	93.3	96.6
edema-polyp	76.6	86.6	81.6	70.0	93.3	81.6	100	96.6	98.3
nodule-palsy	83.3	63.3	73.3	86.6	80.0	83.3	100	93.3	96.6
nodule-polyp	83.3	53.3	68.3	70.0	83.3	76.6	86.6	90.0	88.3
palsy-polyp	46.6	76.6	61.6	50.0	93.3	71.6	93.3	100	96.6
normal-abnormal	89.5	87.6	88.6	89.9	73.6	81.8	100	100	100
benign-malignancy	100	89.1	94.5	100	94.1	97.0	100	94.4	97.1

Overall, the results from a differential diagnosis using the MFCC parameters were

better than those from a differential diagnosis using the MDVP parameters. Given the auditory characteristics of human beings, this shows the advantages that the MFCC parameters have for the differential diagnosis of laryngeal diseases since about 70 percent of laryngeal diseases can be predicted by just listening to the voices of patients. The MFCC and LPC parameters seem to provide more useful information for differential diagnosis than the MDVP parameters. This may be because the MDVP parameters often cannot be determined correctly for the malignant diseases or for benign laryngeal paralysis. That is, if the calculations for pitches is impossible, the calculations for other parameters cannot be done even though there is a lot voice data collected. But the voice characteristics of the MFCC and LPC parameters can show voice characteristics regardless of pitch level and therefore they have greater flexibility than the MDVP parameters in extracting, that is, in calculating parameters.

Differential diagnosis showed the highest rate when the LPC parameters were used as inputs into the artificial neural networks. The LPC parameters that are based on a phonation model showed more useful results from a differential diagnosis than the MFCC parameters that are based on an auditory model. Therefore, we thought that the characteristics of phonation have more significance in differentiating and diagnosing laryngeal diseases than the characteristics of hearing. But as expected, the rates of differential diagnosis for malignant laryngeal diseases, laryngeal paralysis, vocal cord nodules and vocal cord polyps were lower than the classification rates for other diseases. The LPC parameters had an advantage over the other parameters in differential diagnosis. But the parameters still did not show any merits in differentiating and diagnosing malignant diseases and laryngeal paralysis.

4. Conclusion

This study collected voice data from 252 subjects which formed three groups: a group with benign laryngeal diseases (192 patients), another group with malignant laryngeal diseases (41 patients) and a normal control group (19 subjects) without any laryngeal complaints. Then, MDVP parameters, and two additional MFCC and LPC parameters were collected from the production of an open vowel. Using a statistical procedure through the artificial neural networks, we attempted to differentiate laryngeal disease groups. Results showed that Jita, Shim and NHR among the MDVP parameters came out better parameters in diagnosing and differentiating laryngeal diseases while STD, vFo and vAm did not show close relation to the characteristics of the diseases. The auditory MFCC parameters worked better than the MDVP parameters. The LPC parameters excelled the MDVP and MFCC parameters. However, the LPC parameters still could not

differentiate malignant diseases and laryngeal paralysis. Further studies on the relation between the voice and the state of vocal folds would be desirable in promoting a better life of a potential patient with any laryngeal disease.

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