In this chapter PE analysis is carried out using speech signals in different normal and pathological conditions. Vocal sound signals corresponding to Malayalam alphabets from normal as well as abnormal subjects with vocal disorders are analysed. The results clearly distinguish the difference in dynamics between the two cases and the sensitiveness of PE to vocal disorders is established. The results are verified using standard FFT techniques. Maximal Lyapunov exponents are calculated to substantiate the results.
A range of invariant measures that show clearly the low dimensional nonlinear behaviour of individual vowel sounds are introduced in the recent years. The extracted feature from these signals is useful for study and investigation of vocal pathologies. Vocal sound signals are recorded from normal as well as abnormal subjects for different phonemes for PE analysis with an aim of characterising normal and abnormal vocal sound signals.

6.1 SPEECH SIGNAL ANALYSIS

Effectiveness of PE to identify the vocal pathologies is verified on clinically characterized vocal sound data from patients suffering from three different cases. Vocal sound signals are recorded from 3 normal male subjects, 3 normal female subjects and 2 male and 1 female subjects with vocal disorder. The three cases of vocal disorders are of cancer, polyps and laryngitis. The audio signals are converted to digital time series by sampling it at a rate of 11 KHz. These signals are then further analysed using PE for detailed study of qualitative difference in dynamics between normal speech signals and speech signals with disorder. Voiced speech signals of Malayalam viz. "A", "E", "U", are recorded from each subject and the corresponding time series are subjected to PE analysis. The vocal cord vibrations corresponding to these phonemes are different while pronouncing it. PE of order 4 is calculated for moving non overlapping windows of 64 samples for each signal.
Fig. 6.1 (a), 6.1(b) and 6.1(c) represents the variation of PE for letters “A”, “E”, “U” respectively. Normal female subjects are represented by green, normal male subjects are represented by blue, abnormal male represented by black and abnormal female represented by red. Results of the analysis clearly indicate that PE values of normal subjects are lower than that of abnormal cases. The results of the analysis indicate that irrespective of the gender as well as pathological condition PE values are higher for abnormal cases. This property of increased irregularity is identical for all the three sound signals. The higher values of PE of pathological subjects indicate that with abnormalities in voice signals, irregularities in speech signals increases. This reinforces the concept of presence of bifurcations leading to chaos in signals of vocal disorders.

From these results it is clear that PE is effective in characterising the amount of disorder in the vocal pathologies. This characteristic of PE can be made useful in the preliminary investigation of vocal disorders in clinical applications. This can be used as a tool by the clinicians during follow ups for identifying and evaluating the effect of any treatment given to the patients. At every level of treatment the PE data can be stored in the data bank of the patients and can be compared to the PE data before starting the treatment. This may also give first hand information in diagnosis about the level of disorder in pre and post treatment conditions. Hence it can be concluded that PE can be used as an indicator in deciding the final strategy of treatment in vocal pathological cases.
Fig 6.1 (a) Variation of PE for letter “A” (b) Variation of PE for letter “E” (c) Variation of PE for letter “U”
Fig 6.2 (a) FFT for letter “A” (b) FFT for letter “E” (c) FFT for letter “U” for abnormal subject
To confirm the results of PE in speech signals, FFTs corresponding to three letters “A”, “E”, and “U” of pathological case as well as normal subject are calculated. Fig 6.2 (a), (b) and (c) show the Fourier transform of the signals of a pathological case corresponding to plosive and Fig 6.3 (a), (b) and (c) show the Fourier transform of the signals of a normal subject. The FFT indicates that in the case of subjects with vocal disorder, the vocal signals are highly irregular with large number of dominant peaks. In contrast, the FFT of normal subject shown in Fig 6.3 contains fewer prominent peaks. This nature of the FFT shows the regularity in the dynamics of vocal signals of normal subjects. These results reinforce the concept of prediction entropy, having comparatively lower values for dynamically regular behavior. Increase in irregularity as indicated by rise in PE is confirmed by the results of (b) and (c). In order to verify the results maximal Lyapunov Exponents for the signals are calculated using the software tool TISEAN [159]. The Lyapunov exponents corresponding to abnormal speech signal gives positive values which again confirm the irregularity due to vocal pathology.

6.2 SUMMARY

Fig 6.3 (a) FFT for letter “A” (b) FFT for letter “E”
(c) FFT for letter “U” for normal subject
To confirm the results of PE in speech signals, FFT corresponding to three letters “A”, “E”, and “U” of pathological case as well as normal subject are calculated. Fig 6.2 (a), (b) and (c) show the Fourier transform of the signals of a pathological case corresponding to pollips and Fig 6.3 (a), (b) and (c) show the Fourier transform of the signals of a normal subject. The FFT indicates that in the case of subjects with vocal disorder, the vocal signals are highly irregular with large number of dominant peaks. In contrast, the FFT of normal subject shown in Fig 6.3 contains fewer prominent peaks. This nature of the FFT shows the regularity in the dynamics of vocal signals of normal subjects. These results reinforce the concept of permutation entropy, having comparatively lower values for dynamics with regular behavior. Increase in irregularity as indicated by rise in PE is confirmed by the presence of frequency components in Fig. 6.2(a), (b) and (c). In order to verify the results maximal Lyapunov Exponents for the signals are calculated using the software tool TISEAN [159]. The Lyapunov exponents corresponding to abnormal speech signal gives positive values which again confirm the irregularity due to vocal pathology.

6.2 SUMMARY

PE based analysis is carried out in speech signal to study the change in dynamics due to vocal disorders. Results show that PE for normal subjects are low compared
to that of pathological cases where the dynamical behaviour is irregular. These results are verified using the standard linear method of FFT. Positive Lyapunov exponents corresponding to phonemes of abnormal subjects indicate chaotic behaviour.