CHAPTER 6 - SUMMARY, CONCLUSIONS AND FUTURE DIRECTIONS

Medical fields require fast, simple and noninvasive methods of diagnostic techniques. Several methods are available because of the growth of technology. To understand the complexity of voice signals, new methods of analysis have been developed, such as nonlinear dynamics aiming at the exploration of voice signals dynamic nature. The work presented in this thesis focuses on characterization of healthy and pathological voice signals with the aid of modern nonlinear methods like maximum Lyapunov exponent, correlation dimension, kolmogorov entropy and a fast and robust entropy measure Permutation Entropy (PE). Nonlinear dynamical methods seem to be a suitable technique for voice signal analysis. Among the nonlinear parameters investigated lyapunov exponent and PE show relatively better performance in characterizing the difference in dynamics between normal and abnormal speech signal.

The results of acoustic as well as nonlinear analysis on individual vowels and continuous speech data indicate the efficiency of nonlinear measures in characterizing the change in dynamics of stuttered speech after a specific period of speech therapy. Conventional nonlinear measures like correlation dimension and kolmogorov entropy do not perform very well on raw data indicating dynamical changes. In the case of post-treatment of vowels and continuous speech data, the conventional nonlinear measures like Correlation dimension (D_2) and Kolmogorov entropy (K_2) do not perform very well. These measures being sensitive to non-stationarity and noise contamination produce ambiguous results mainly due to the presence of silent blocks in trained speech of stuttering subjects. Among the conventional nonlinear measures maximum lyapunov exponent performs slightly better. The newly introduced entropy measure mainly permutation entropy shows efficiency in indicating the improvement in speech performance after the therapy. The robustness of this measure to noise

contamination and non-stationarity helps this measure in effectively characterizing the level of improvement in speech process after therapy. PE being a bounded measure is more efficient in comparing different methods of therapy.

The specific ability of nonlinear parameters in characterizing the difference in dynamics is evident in the results of analysis on vocal pathologies also. Among the nonlinear parameters max lyapunov exp and PE are better indicators of the increased dynamical complexity of pathological voice signals. The simplicity and speed of computation of PE enhances its suitability for application in online evaluation setup. Robustness of this measure towards noise and non-stationarity add to its efficiency in characterizing the dynamical difference between normal and pathological, fluent and disfluent speech signals.

The versatile and invariant properties of Permutation Entropy (**PE**) helped us to meet our aims listed below

1. To compare and analyse voice signals using traditional perturbation and nonlinear dynamics time series methods for stutterers and vocal disorder subjects .
2. To Characterise stutterred signals from fluent signals.
3. To estimate the efficacy of speech therapy rendered to stuttered subjects.
4. To Characterise Pathological signals from healthy signals.

6.1 SUMMARY AND CONCLUSION

This thesis presents an analysis of speech signals of different groups of subjects viz., subjects with stuttering, normal subjects and subjects with vocal fold pathologies. Voice signal analysis is carried out using traditional acoustic analysis methods as well as nonlinear time series analysis methods. The results of our analysis helped in distinguishing fluent speech from stuttered speech and the abnormal speech subjects with vocal pathologies from that of normal subjects. The results brings out the effectiveness of nonlinear methods compared to the perturbation methods in characterizing different voice signals . These results suggest that nonlinear analysis method can be beneficial in classifying pathological and disfluent speech signal. The appropriateness of PE for characterizing vocal signals on line clinical setup is also clearly revealed.

To summarise the achievements

1. Application of PE For detection of dynamical change in speech process is carried out.
2. Lower values of PE indicates the presence of repeated blocks of phonemes in speech signal of stuttering subjects.
3. Results are used for judgement of patient performance before and after speech therapy sessions in case of stuttering subjects. This helps in assessing the amount of improvement before and after treatment
4. PE effectively characterize vocal pathologies also .
5. PE values corresponding to abnormal voice is higher indicating increase in irregularity. Increase in PE indicates an increase in irregularity.
6. PE gives reliable results in the presence of noise.
7. Calculation time for PE for window size 512 samples of order 5 is less than nanoseconds.
8. Results obtained using PE analysis is compared with the existing acoustic measures of Jitter, Shimmer , Zero crossing, and fundamental frequency F0.

6.2 FUTURE SCOPE

In this thesis we have presented the result of our analysis of different speech signals of stutterers as well as subjects with vocal disorders. With an aim of characterizing these signals. The results of speech signal analysis using conventional perturbation analysis and nonlinear time series analysis methods are compared for assessing their applicability in an online evaluation setup. However, this work is still an initial study of the subject . Further work along this line can help in modifying and perfecting the approach of PE for online evaluation application. Also further work in investigating the dynamical changes introduced by pathologies in comparision with that of normal voice production will help in better diagnosis thereby increasing the efficiency of treatment modalities. Such methods if combined with the existing analysis tools will help in better classification and early diagnosis of different types of vocal disorders. Such approach will certainly improve the assessment efficiency of existing methods in determining the changes in improvement in speech quality rendered by different therapy methods.

Also the effectiveness of PE for various different pathological conditions can be investigated. The efficiency of other predictability measures can be investigated for a better understanding of the relation of pathologies with the complexity of the voice signals. Furthermore the interconnection between brain dynamics and stuttering is a potential field to be investigated. This can shed light into dynamics/dynamical changes of stuttered speech production.