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Conclusions and Future Works

7.1 CONCLUSIONS

The thesis work has focused to propose a system that is robust against real-life noises and convenient to subjects for its long-term use. Such features of the system would be useful for frequent monitoring of the heart without a need to visit a clinic and, hence, would be favourable to diagnose the CVDs at an early stage. Therefore, in this thesis, various contributions have been made to improve the robustness of the system against real-life noises and to improve the convenience of the subject for long-term use. Following are the conclusions of the works which have been presented in this thesis.

The thesis work started with a detailed review of recent advancements in the portable heart monitoring systems for their suitability in real-life scenarios. The review concludes that the heart sound signal based heart monitoring systems, PCG and SCG, provide ample diagnostic features in a cost-effective manner, and moreover, these systems are easy to use and hence user-friendly. In addition to these features, a system which has to be used in the real-life scenario should be robust to noises generated due to internal and external noise sources. To show the applicability of PCG and SCG in real-life scenarios, performances of both the systems have been analysed in various real-life scenarios and presented in Chapter 2. The time and time-frequency domain analysis have demonstrated the correlation between the heart sound components in the PCG signal and in the SCG signal. This expresses the ability of SCG to acquire the heart sound signal. The qualitative and quantitative analyses have shown the robustness of the SCG signal. The major reasons behind its robustness are that it does not require a microphone, and small size and light weight of its sensor are in favour of good attachment to the chest wall. Further, the accelerometer has a flat frequency response. These merits make the SCG signal robust to various noises. Besides the robustness of the SCG, the requirement to improve the SNR was observed especially in the case of 'walking' scenario, where noise components were present in the SCG signal due to footsteps.

In view of the noise contamination, two methods to suppress the noise from the heart sound signal have been presented in chapter 5. One is based on DWT, which adaptively thresholds the wavelet coefficients of the heart sound signal. The major contribution of the work is the estimation of the threshold adaptively, according to the presence of noise level. To further improve the performance of the algorithm, a non-linear mid threshold function has been presented. The results obtained from the experiments show the effectiveness of the proposed method to suppress the level of noise. Another denoising method is proposed in the same chapter to address the noise contamination of the SCG signal in 'walking' scenario. Both the methods are proposed to be used in the combination to remove the noise as well as undesired signatures due to footsteps. In view of the importance to suppress the murmur from the FHS, the proposed method has been applied to the signals with murmur as well. In most cases, the proposed method suppresses the murmur effectively, although in few cases of murmurs, the limitation of the DWT based method was observed due to the constant Q-factor.

To address the issues of the constant Q-factor of WT, in Chapter 5, a robust segmentation algorithm for the heart sound signal is proposed based on TQWT. Three reasons were observed that contributed towards the enhancement of robustness of the method. First one is the discarding of the approximation level by which most of the real-life noise components get discarded. The second reason is the use of Fano factor that effectively selects a level with the low level of noise. The third reason is the adaptive thresholding of the selected level and that suppresses the low amplitude noise components efficiently. The obtained results have shown the accuracy of the method to segment the heart sound signal even in the presence of noise and murmurs. In addition to it, the computational complexity of the proposed method was observed lower than the recently reported method C-TQWT.

In the last chapter, a novel system for the estimation of the E-M window using ECG and SCG has been presented. The system is convenient to wear due to the small size and low weight of the accelerometer and the placement of the sensors. The obtained results show that the SCG can be a suitable alternative to the PCG.

The thesis presented various contributions to improve the robustness of the system against real-life noises and to make the system convenient to the subject for long-term use. In addition to these contributions, following possibilities were observed for future enhancements.

7.2 RECOMMENDATIONS FOR FUTURE WORKS

The possible extension of the above work that can be done in the future are listed below:

- **Classification of the heart sound signal for a specific disease:** The work can be extended to classify the heart sound signal for a specific disease. For this purpose, the feature can be extracted from the segmented cardiac cycle using the proposed method. These features can be used as an input for classification.

- **Consideration of extreme noise cases for noise removal algorithm:** In the proposed algorithms, various types of noise such as screaming of people, vehicle noise, motion of the subject, speaking of the subject, and walking of the subject, have been considered for the noise removal. Further, extreme noise cases such as running or jumping of the subject can be considered. It is expected that these types of noises will have a specific signature in the recorded signal and hence these signatures can be used to identify them in the signal and to remove them.

- **Development of a wearable device for the assessment of the E-M window and validation of it for the pathological cases:** As presented in Chapter 6, the developed system for the assessment of the E-M window is robust to noise and easy to wear for long-term use. The future task includes the development of a wireless module and its validation for various pathological cases.

- **Exploration of Seismocardiography to analyse heart valve diseases:** SCG signal has shown its capability to diagnose various cardiovascular diseases. The Importance of SCG can also be explored for various diagnostic purposes including heart valve diseases and blood pressure.

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