

List of Figures

<i>Figures</i>	<i>Title</i>	<i>page</i>
1.1	Mortality due to CVDs, Worldwide	1
1.2	Anatomy of the human heart	3
1.3	Echocardiography	5
1.4	Single cardiac cycle represented by ECG	5
1.5	Single cardiac cycle represented by PCG	6
1.6	Single cardiac cycle represented by PPG	7
1.7	Single cardiac cycle represented by ICG	7
1.8	Single cardiac cycle represented by SCG	8
2.1	Heart monitoring system	13
2.2	Block diagram of Off-site heart monitoring system	14
3.1	Schematic diagram of the stethoscope	31
3.2	Schematic diagram of the MEMS accelerometer	33
3.3	Heart sound signal acquisition using PCG and SCG systems	33
3.4	System setup for signal acquisition using (a) PCG, (b) SCG, and (c) ECG	34
3.5	Time domain representation of signals: (a) ECG, (b) PCG, (c) SCG, (d) Ensemble averaged PCG, and (e) Ensemble averaged SCG	35
3.6	Power spectrum of signals: (a) PCG signal and (b) SCG signal	36
3.7	(a) PCG signal, (b) Wavelet scalogram of PCG signal, (c) SCG signal, and (d) Wavelet scalogram of SCG signal	38
3.8	Colour coding for the scalogram.	38
3.9	Signals for ‘Clinical’ scenario: (a) ECG signal, (b) PCG signal, (c) Filtered PCG signal, (d) Averaged filtered PCG signal, (e) Detected points in PCG signal, (f) SCG signal, (g) Filtered SCG signal, (h) Averaged filtered SCG signal, and (i) Detected points in SCG signal	39
3.10	Signals for ‘in meeting’ scenario: (a) ECG signal, (b) PCG signal, (c) Filtered PCG signal, (d) Averaged filtered PCG signal, (e) Detected points in PCG signal, (f) SCG signal, (g) Filtered SCG signal, (h) Averaged filtered SCG signal, and (i) Detected points in SCG signal	40
3.11	Signals for ‘walking’ scenario: (a) ECG signal, (b) PCG signal, (c) Filtered PCG signal, (d) Averaged filtered PCG signal, (e) Detected points in PCG signal, (f) SCG signal, (g) Filtered SCG signal, (h) Averaged filtered SCG signal, and (i) Detected points in SCG signal	41
3.12	Signals for ‘motion of patient’ scenario: (a) ECG signal, (b) PCG signal, (c) Filtered PCG signal, (d) Averaged filtered PCG signal, (e) Detected points in PCG signal, (f) SCG signal, (g) Filtered SCG signal, (h) Averaged filtered SCG signal, and (i) Detected points in SCG signal	42
3.13	Signals for ‘travelling’ scenario: (a) ECG signal, (b) PCG signal, (c) Filtered PCG signal, (d) Averaged filtered PCG signal, (e) Detected points in PCG signal, (f) SCG signal, (g) Filtered SCG signal, (h) Averaged filtered SCG signal, and (i) Detected points in SCG signal	43

3.14	Signals for ‘in market’ scenario: (a) ECG signal, (b) PCG signal, (c) Filtered PCG signal, (d) Averaged filtered PCG signal, (e) Detected points in PCG signal, (f) SCG signal, (g) Filtered SCG signal, (h) Averaged filtered SCG signal, and (i) Detected points in SCG signal	44
3.15	‘Clinical scenario’ signals: (a) ECG signal, (b) Filtered PCG signal, (c) S1 and S2 in PCG signal, (d) Rest of the cycle in PCG signal, (e) Filtered SCG signal, (f) S1 and S2 in SCG signal, and (g) Rest of the cycle in SCG signal	45
4.1	Block diagram of the DWT based denoising algorithm	52
4.2	Reconstructed signal at various detailed levels and approximation level	53
4.3	Statistical parameters for the signal with added white Gaussian noise: (a) med_{75} at two different SNR values and (b) med_{75} and median values at various SNR values	54
4.4	Statistical parameter analysis for the wavelet coefficients (detailed level-4) in three different cases (a) Low level of noise, (b) Moderate level of noise, and (c) Highly noisy	55
4.5	Statistical parameters (mean, Med_{75} , and variance) of the wavelet coefficients (detailed level-4) of signal contaminated with white Gaussian noise at various levels	55
4.6	Output response of the soft, hard and mid threshold functions.	56
4.7	Peak detection and identification: (a) PCG signal, and (c) envelope of the signal with identified components	58
4.8	Denoising results for soft, hard, mid, and non-linear mid threshold functions with various thresholds estimated by different methods: (a) ‘sqrtwolog’, (b) ‘rigrsure’, (c) ‘heursure’, (d) ‘minimaxi’, (e) and (f) proposed threshold estimation method	60
4.9	Results for PCG signals of different subjects with AWGN: (a) Detection rate of S1, (b) Detection rate of S2, and (c) Number of false points	61
4.10	Obtained denoising results for the PCG signal contaminated with pink and red noise: (a) Clean signal, (b) Noisy signal, (c) DWT-A, (d) DWT-B, and (e) Proposed method	62
4.11	SNR and fit values for the denoised PCG signal contaminated with pink and red noise	62
4.12	Detection rate of S1 and S2 and number of false points in the denoised PCG signal contaminated with pink and red noise.	62
4.13	Denoising results for the recorded PCG signal in noise scenario using various methods: (b) DWT-A, (c) DWT-B, and (d) Proposed method	63
4.14	Denoising results for the recorded PCG signal in ‘walking’ scenario using various methods: (b) DWT-A, (c) DWT-B, and (d) Proposed method	64
4.15	Results of various methods to remove murmurs from the PCG signal; (a) murmur signal, (b) DWT- A method, (c) DWT-B method, and (d) Proposed method	64
4.16	Signals for speaking scenario: (a) Acquired z-axis signal, (b) Filtered z-axis signal, (c) Acquired x-axis signal, and (d) Filtered x-axis signal	66
4.17	Signals for motion scenario: (a) Acquired z-axis signal, (b) Filtered z-axis signal, (c) Acquired x-axis signal, and (d) Filtered x-axis signal	67
4.18	Signals for walking scenario: (a) Acquired z-axis signal, (b) Filtered z-axis signal, (c) Acquired x-axis signal, and (d) Filtered x-axis signal	67
4.19	Block diagram of the proposed method	68
4.20	Noise components in z-axis due to footsteps: (a) Noise component, (b) Noise component after the heart sound component, and (c) Noise component before the heart sound component	69
4.21	Obtained results for ‘in motion’ scenario: (a) Acquired z-axis signal, (b) Acquired x-axis signal, and (c-e) Identified peaks in the filtered z-axis signal using DWT (c), polynomial smoothing filtering (d), and (e) the proposed method	70
4.22	Obtained results for ‘walking’ scenario: (a) Acquired z-axis signal, (b) Acquired x-axis signal, and (c-e) Identified peaks in the filtered z-axis signal using DWT (c), polynomial smoothing filtering (d), and (e) the proposed method	70

5.1	Decomposition of the signal using TQWT	76
5.2	Characteristics of the filters used in TQWT decomposition	77
5.3	Block diagram of the proposed method	77
5.4	Analysis of quality indices in two different cases of pathological signals at two different levels, decomposed using TQWT	80
5.5	Analysis of denominator and numerator terms of Fano factor and kurtosis for signal with various SNR, due to AWGN	80
5.6	PCG signal of a normal case	82
5.7	Obtained results using the proposed method with different quality indices for the PCG signal contaminated with various types of noise: (a) noisy signal, (b) Results using kurtosis, and (c) Results using Fano factor. The Roman numbers (i) and (ii) represent reconstructed signal at a selected basis level and its envelope using NASE, respectively	83
5.8	Obtained segmentation rate (%) using the proposed method with kurtosis and Fano factor, for the signal contaminated with various types of noise at various levels.	83
5.9	Obtained results for the PCG signal contaminated with various types of noise: (a) noisy signal, (b) Results using WT method, (c) Results using C-TQWT method, and (d) Results using proposed method. The Roman numbers (i) and (ii) represent reconstructed signal at selected basis level and its envelope using NASE, respectively	84
5.10	Obtained segmentation rate (%) using various methods for the signal contaminated with various types of noise at various levels	84
5.11	Results obtained for the PCG signal with murmur sounds: (a) PCG signal with murmur, (b) Results using WT method, (c) Results using C-TQWT method, and (d) results using proposed method. The Roman numbers (i) and (ii) represent reconstructed signal at selected basis level and its envelope using NASE, respectively	85
6.1	Measurement of E-M window	90
6.2	The proposed system setup	91
6.3	System setup for signal acquisition using (a) PCG, (b) SCG and (c) ECG	91
6.4	The acquired signals (a) ECG, (b) SCG, and (c) PCG	92
6.5	The graphical user interface for the estimation of E-M window	93
6.6	Bland Altman plot between the SCG and the PCG: (a) to measure QS ₂ -QT duration and (b) to measure QT/QS ₂ ratio	94

