

## List of Figures

Fig. 1.1 Requirements of speech enhancement methods .....	1
Fig. 2.1 A chart showing summary of existing speech enhancement methods .....	15
Fig. 2.2 Block diagram of adaptive noise cancellation (ANC) system .....	25
Fig. 2.3 Flow chart for implementation of ANC using NLMS algorithm.....	27
Fig. 2.4 SIMULINK implementation of ANC using NLMS algorithm .....	29
Fig. 2.5 Hardware setup for implementation on DSK 6713 .....	31
Fig. 2.6 DSK 6713 implementation of ANC using NLMS algorithm .....	31
Fig. 2.7 SIMULINK model to obtain learning curves of ANC using NLMS algorithm.....	34
Fig. 2.8(a) Learning curves for NLMS algorithm with $\tilde{\mu} = 0.001$ .....	35
Fig. 2.8(b) Learning curves for NLMS algorithm with $\tilde{\mu} = 0.01$ .....	36
Fig. 2.8(c) Learning curves for NLMS algorithm with $\tilde{\mu} = 0.1$ .....	37
Fig. 2.8(d) Learning curves for NLMS algorithm with $\tilde{\mu} = 1.0$ .....	38
Fig. 2.8(e) Learning curves for NLMS algorithm with $\tilde{\mu} = 1.5$ .....	39
Fig. 2.9 Echo cancellation using NLMS algorithm - SIMULINK model .....	41
Fig. 3.1 STFT of speech signal.....	45
Fig. 3.2 Overlap add synthesis with 50% overlap (L=500, R=L/2) .....	48
Fig. 3.3 Flow chart of analysis-modify-synthesis method.....	49
Fig. 3.4 Time domain waveform of speech signal containing sentence ‘He knew the skill of the great young actress’ .....	51
Fig. 3.5 Narrowband (top panel) and wideband (bottom panel) spectrogram of the speech signal in figure 3.4 .....	51
Fig. 3.6 A chart showing various STSA algorithms.....	52
Fig. 3.7 Block representation of general spectral subtraction method .....	54
Fig. 3.8 Block diagram of MBSS method.....	58
Fig. 3.9 Voice active and inactive regions .....	63
Fig. 3.10 Block diagram of VAD and noise estimation .....	63

Fig. 3.11 Objective speech quality measuring system.....	70
Fig. 3.12 Block diagram of PESQ measure computation .....	72
Fig. 4.1 A flow chart showing general implementation of STSA algorithms	75
Fig. 4.2 Flow chart for MSS and PSS implementation.....	76
Fig. 4.3 A block diagram for BSS implementation .....	77
Fig. 4.4 Flow chart for magnitude spectral distance VAD implementation....	79
Fig. 4.5 Spectrogram of clean speech signal containing sentence ‘He knew the skill of the great young actress’ (top panel) and spectrogram of the signal subjected to 0dB white noise (bottom panel) .....	80
Fig. 4.6 Spectrogram of enhanced speech signal using various algorithms indicated on the head of each panel .....	82
Fig. 4.7 SSNR comparison of STSA algorithms over NOIZEUS database ....	89
Fig. 4.8 WSS comparison of STSA algorithms over NOIZEUS database.....	90
Fig. 4.9 LLR comparison of STSA algorithms over NOIZEUS database ..	91
Fig. 4.10 PESQ comparison of STSA algorithms over NOIZEUS database ..	92
Fig. 4.11 Objective evaluation of STSA algorithms under white noise.....	93
Fig. 4.12 MATLAB GUI for STSA algorithms .....	94
Fig. 4.13 Objective evaluation of wavelet algorithms under white noise .....	96
Fig. 5.1 General shape of the masking threshold curve for a masking tone at frequency $\Omega_0$ .....	100
Fig. 5.2 Block diagram: RASTA processing system .....	104
Fig. 5.3 Frequency response of fixed IIR RASTA filter .....	105
Fig. 5.4 Flow diagram of RASTA processing for de-convolution.....	106
Fig. 5.5 Impulse response of multiband 21 taps FIR filters for additive noise removal in RASTA processing.....	107
Fig. 5.6 Flow diagram of RASTA processing for additive noise removal ( $b=1/a=\gamma$ ).....	108
Fig. 5.7 Design of multiband RASTA filter in 300-2300Hz band.....	109
Fig. 5.8 Design of multiband RASTA filter in 100-300Hz and 2300-4000Hz band .....	110

Fig. 5.9 Frequency response of multiband RASTA filter in 300-2300Hz band .....	110
Fig. 5.10 Frequency response of multiband RASTA filter in 100-300Hz and 2300-4000Hz band .....	111
Fig. 5.11 SSNR comparison of RASTA algorithms over NOIZEUS database .....	114
Fig. 5.12 WSS comparison of RASTA algorithms over NOIZEUS database .....	115
Fig. 5.13 LLR comparison of RASTA algorithms over NOIZEUS database .....	116
Fig. 5.14 PESQ comparison of RASTA algorithms over NOIZEUS database .....	117
Fig. 5.15 Objective evaluation of RASTA algorithms under white noise conditions.....	118
Fig. 5.16 Spectrogram of enhanced speech signal using various RASTA algorithms containing sentence ‘He knew the skill of the great young actress’ .....	119
Fig. 6.1 Block diagram of proposed speech enhancement method.....	122
Fig. 6.2 Spectrogram of enhanced speech signal using proposed approach..	123
Fig. 6.3 SSNR comparison of proposed algorithm over NOIZEUS database .....	125
Fig. 6.4 WSS comparison of proposed algorithm over NOIZEUS database.	126
Fig. 6.5 LLR comparison of proposed algorithm over NOIZEUS database .	127
Fig. 6.6 PESQ comparison of proposed algorithm over NOIZEUS database .....	128
Fig. 6.7 Objective evaluation of proposed algorithm under white noise.....	129
Fig. 6.8 Pro forma for filling up the MOS .....	132
Fig. 6.9 Results of MOS test.....	133
Fig. 7.1 Functional block and CPU (DSP core) diagram of C6713 .....	142
Fig. 7.2 DSK 6713 block diagram .....	143
Fig. 7.3 AIC- DSP interface .....	144
Fig. 7.4 Working of code composer studio .....	145

Fig. 7.5 Role of real time workshop .....	148
Fig. 7.6 Working of real time workshop.....	149
Fig. 8.1 Typical hardware and software setup for developing models .....	152
Fig. 8.2 SIMULINK block for real time implementation of hybrid algorithm on PC .....	153
Fig. 8.3 Internals of sub-system data buffering and windowing .....	154
Fig. 8.4 Internals of sub-system hybrid algorithm.....	154
Fig. 8.5 Internals of sub-system overlap-add synthesis.....	155
Fig. 8.6 Waveforms of clean, noisy and enhanced speech using real time hybrid algorithm.....	155
Fig. 8.7 SIMULINK profile results of hybrid algorithm.....	156
Fig. 8.8 SIMULINK block for real time implementation of hybrid algorithm on DSK6713 .....	157
Fig. 8.9 Profile report of real time implementation of hybrid algorithm on DSK6713 .....	160