International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Performance Evaluation of ICA Methods for Maternal–Fetal ECG Separation Under Noise

Sargam D. Parmar

EC Department, K. D. Polytechnic, Patan, Gujarat, India

Abstract

Reliable extraction of a fetal electrocardiogram (FECG) from recordings taken on the mother's body is difficult because the maternal ECG (MECG) is often much stronger than the fetal signal. This work reviews the comparative behaviour of three independent component analysis (ICA) techniques—Joint Approximate Diagonalization of Eigen-matrices (JADE), Comon's method, and the Optimized Generalized Weighted Estimator (OGWE)—in a simulated blind source separation setting. Maternal and fetal ECG records are mixed linearly and then corrupted by white Gaussian or pink noise. The evaluation varies the maternal-to-fetal amplitude ratio and the noise level. A performance index is used to assess higher-order separation, while signal-to-error ratio (SER) and output signal-to-noise ratio (SNR) provide complementary measures of reconstruction quality. As reported in the source study, all three methods show useful separation under the tested conditions. JADE and OGWE are generally competitive with, and often somewhat stronger than, Comon's method; JADE is also noted for its relatively low computational burden and lack of tuning parameters.

Keywords: Independent component analysis, blind source separation, fetal ECG, maternal ECG, biomedical signals, noise.

1. Introduction

The electrocardiogram is widely used to examine the electrical activity of the heart. In pregnancy, the fetal ECG can provide additional information about fetal cardiac activity, but acquiring it non-invasively is complicated by the presence of the mother's own ECG and other physiological interference. Invasive techniques involving a fetal-scalp electrode are generally associated with labour, which motivates methods that can estimate the fetal signal earlier using electrodes placed on the mother's skin.

A major difficulty is the difference in source strength: the maternal component may be several times to as much as three orders of magnitude larger than the fetal component. Electromyographic activity and measurement noise can further obscure the weaker FECG. Separation methods must therefore recover the fetal waveform from observations containing overlapping sources.

Blind source separation models the measured channels as mixtures of underlying signals. Independent component analysis is particularly relevant when the source signals can be treated as statistically independent and non-Gaussian. The study considered here compares JADE, Comon's algorithm and OGWE, focusing on the effect of source-amplitude imbalance and two forms of additive noise.

2. ICA Model and Processing

The signal model used in the study is x = As + n. Here, x denotes the measured channel vector, s represents the independent source signals, A is an unknown invertible mixing matrix, and n is the added noise. ICA estimates a separating matrix W so that y = Wx approximates the source signals. The recovered components may differ from the originals in scale and order, which are normal ambiguities in ICA.

2.1 Centering and whitening

The observations are first centered by subtracting the mean of each channel. Whitening then transforms the centered data so that the transformed channels are uncorrelated and have unit variance. In the described approach, whitening is based on eigenvalue decomposition of the covariance matrix. This preprocessing reduces second-order dependencies and provides a convenient starting point for the ICA algorithms.

2.2 JADE

JADE exploits second- and fourth-order statistical information. Following whitening, it constructs fourth-order cumulant matrices and jointly diagonalizes selected matrices using a unitary transformation. The resulting transformation provides estimates of the independent components. The source paper highlights that JADE avoids gradient-descent divergence and does not require tuning learning parameters, contributing to its practical computational advantages.

2.3 Comon's method

Comon's algorithm is based on a contrast function that reduces mutual information among the separator outputs. Mutual information measures statistical dependence; reducing it encourages the estimated components to become independent. The paper describes a formulation involving marginal cumulants, with the fourth-order case connected to squared kurtosis.

2.4 Optimized Generalized Weighted Estimator

OGWE formulates a marginal-entropy contrast using second- and fourth-order cumulants. After the input has been whitened, the method calculates rotations for pairs of components. Rotations are applied when their estimated angles exceed a minimum threshold, and the rotation matrix is updated through iterations. The final demixing transformation is then used to estimate the source signals.

3. Experimental Design

3.1 ECG data and amplitude ratios

The experiments use two ECG records from the MIT–BIH database, sampled at 360 Hz. One record represents the maternal source and the other the fetal source. To model the weaker fetal waveform, the FECG amplitude is reduced relative to the MECG, using maternal-to-fetal ratios of 10, 50, 100, 500 and 1000. The records are mean-centered and normalized before the amplitude adjustment. The fetal waveform is also described as having twice the cycles per second of the maternal waveform.

3.2 Mixing and noise conditions

The two sources are combined linearly to form simulated electrode observations. White Gaussian noise is generated in MATLAB, while pink noise is produced through a Fourier-domain generator with a pink-noise spectrum. Noise is added at specified input SNR values measured against the mixed channel. Testing both noise types allows the algorithms to be compared under different spectral characteristics.

3.3 Evaluation measures

The study uses a performance index derived from the global system matrix P = WA to evaluate higher-order separation. A value of zero corresponds to ideal separation under the defined criterion. The signal-to-error ratio is also considered as a second-order measure, with the estimated signal aligned in phase and energy with the target before the error is calculated. Output SNR plots are used to discuss the recovered MECG and FECG.

4. Results and Discussion

The paper reports results for MECG and FECG recovery with Gaussian and pink noise across the five amplitude ratios. In the MECG experiments, output SNR generally improves as the maternal-to-fetal ratio rises from 10 to 100. At larger ratios, JADE and OGWE show favourable performance in the reported comparisons, particularly over selected input-SNR ranges.

For the fetal component, all three algorithms are reported to recover useful information when the input SNR is approximately 10 dB or below. The paper notes that the fetal R wave can still be extracted when the input SNR approaches 0 dB. Nevertheless, increasing the maternal-to-fetal amplitude ratio makes FECG recovery more difficult and tends to reduce its output SNR.

The study finds broadly similar overall behaviour for white Gaussian and pink noise. Performance-index results show a peak in roughly the 0–8 dB input-SNR region, although the location of this peak changes with the amplitude ratio. When noise becomes dominant, separation quality deteriorates, particularly in the reported 0–5 dB range. Comon's method is described as slightly less effective overall than JADE and OGWE, while JADE is singled out for its low computational cost and lack of parameters requiring tuning.

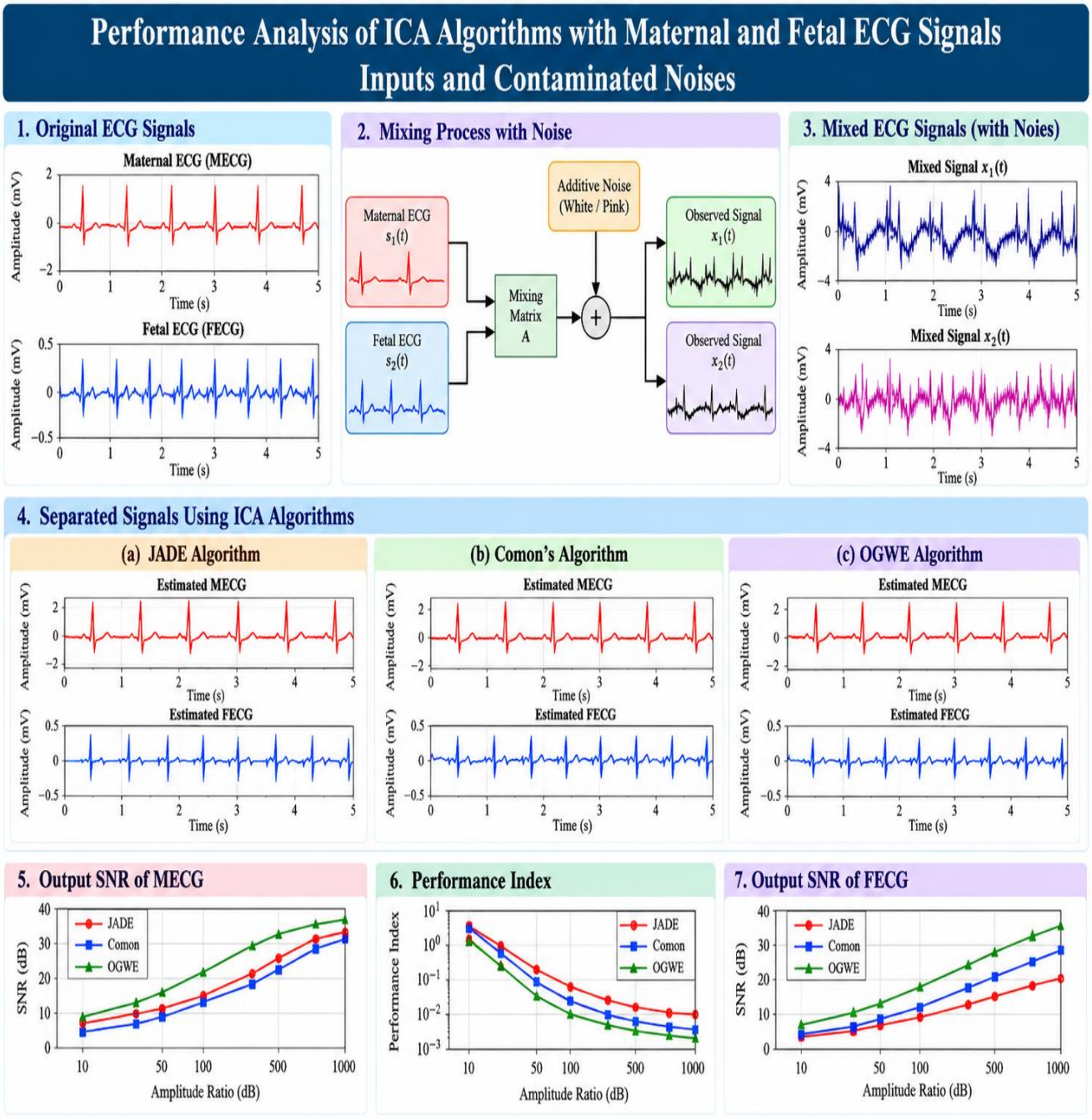
These findings should be interpreted within the study's simulated setting. The reported experiments support a comparison of the three methods under controlled mixtures; they do not, by themselves, establish clinical performance on real-world recordings.

5. Conclusion

This comparison examines JADE, Comon's algorithm and OGWE for separating maternal and fetal ECG components from noisy linear mixtures. The results described in the source paper indicate that all three approaches can provide useful separation when the added noise does not overwhelm the mixture. Changing the maternal-to-fetal amplitude ratio affects the quality of recovery, whereas the choice between white Gaussian and pink noise has a comparatively limited effect on the overall ranking. JADE and OGWE generally compare favourably with Comon's method, and JADE offers a practical advantage through low computational cost and no tuning parameters. Further validation using clinical recordings would be needed before drawing conclusions about real-world diagnostic use.

References

1. Kam, A., and Cohen, A. (1998). "Maternal ECG elimination and foetal ECG detection—Comparison of several algorithms." Proceedings of the 20th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 20(1), 174–177.
2. Zarzoso, V., and Nandi, A. (2001). "Noninvasive fetal ECG extraction: Blind separation versus adaptive noise cancellation." IEEE Transactions on Biomedical Engineering, 48(1), 12–18.
3. Parmar, S. D., and Sahambi, J. S. (2004). "A comparative survey on removal of MECG artifacts from FECG using ICA algorithms." Proceedings of ICISIP 2004, Chennai, India, 88–91.
4. Choi, S., Cichocki, A., and Amari, S. (2000). "Flexible independent component analysis." Journal of VLSI Signal Processing.
5. Parmar, S. D., and Unhelkar, B. (2008). "Separation performance of ICA algorithms in FECG and MECG signals contaminated by noise." Proceedings of ICCCN 2008, Karur, India.
6. Parmar, S. D., and Unhelkar, B. (2010). "Performance of Optimized Generalized Weighted Estimator ICA algorithm on biomedical signals contaminated by noise." International Journal of Computer Applications, 1(2), 29–33.
7. Cardoso, J. F., and Souloumiac, A. (1993). "Blind beamforming for non-Gaussian signals." IEE Proceedings F, 140(6), 362–370.
8. Cardoso, J. F. (1997). "Higher-order contrasts for independent component analysis." Neural Computation, 11(1), 157–192.
9. Comon, P. (1994). "Independent component analysis, a new concept?" Signal Processing, 36(3), 287–314.
10. Comon, P. (1996). "Contrasts for multichannel blind deconvolution." IEEE Signal Processing Letters, 3, 209–211.
11. Murillo-Fuentes, J. J., Boloix-Tortosa, R., and González-Serrano, F. J. (2003). "Initialized Jacobi optimization in independent component analysis." Proceedings of ICA 2003, Nara, Japan, 1053–1058.
12. Jutten, C., and Herault, J. (1991). "Blind separation of sources, Part I: An adaptive algorithm based on neuromimetic architecture." Signal Processing, 24, 1–10.
13. MIT–BIH Arrhythmia Database. Available at: http://ecg.mit.edu.
14. Potter, M., Gadhok, N., and Kinsner, W. (2002). "Separation performance of ICA on simulated EEG and ECG signals contaminated by noise." Proceedings of the 2002 IEEE Canadian Conference on Electrical and Computer Engineering, 1099–1104.


Performance Analysis of ICA Algorithms with Maternal and Fetal ECG Signals Inputs and Contaminated Noises
1. Original ECG Signals
Maternal ECG (MECG)
Fetal ECG (FECG)
Amplitude (mV)
Time (s)
2. Mixing Process with Noise
Maternal ECG $s_1(t)$
Fetal ECG $s_2(t)$
Additive Noise (White / Pink)
Mixing Matrix A
Observed Signal $x_1(t)$
Observed Signal $x_2(t)$
3. Mixed ECG Signals (with Noies)
Mixed Signal $x_1(t)$
Mixed Signal $x_2(t)$
4. Separated Signals Using ICA Algorithms
(a) JADE Algorithm
(b) Comon's Algorithm
(c) OGWE Algorithm
Estimated MECG
Estimated FECG
5. Output SNR of MECG
SNR (dB)
Amplitude Ratio (dB)
JADE
Comon
OGWE
6. Performance Index
Performance Index
7. Output SNR of FECG