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TWIN FETUS ECG SIGNAL EXTRACTION BASED ON TEMPORAL PREDICTABILITY

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ABSTRACT

The most popular defects that infect new born babies have close connection with heart. Approximately 1% percent of new born babies suffering from defects that are caused by heart. By observing Electrocardiogram "ECG" during gestation doctors can study the fetal heart activity that collected from mother abdominal and rectify number of defects which has been diagnosed in fetal heart. Many techniques like filters, BSS and even artificial intelligence used to extract and process fetal ECG signal. In case of twins gestation the problem would be more complicated because the recorded signal is a mixture of multi signals which are mother ECG, fetuses ECG and noises where every signal comes from different source in addition fetus have the same ECG signal features as well. In this study the concentration would be on BSS techniques specifically on Stone BSS method. A comparison has been made between Stone method and two other methods "EFICA and JADE". The results proved that Stone method has better performance comparing to the other BSS techniques.

KEYWORDS: FECG; MECG; Blind Source Separation (BSS); EFICA; JADE

1. INTRODUCTION

Observing fetal through ECG provides the necessary information to check on the status of the fetal. There are two methods to get the fetal electric diagram FECG. Invasive and non- invasive, in case of invasive labors are used to connect the electrodes to the head of the fetal (scalp) inside the uterus where the signals record directly from the mother abdomen. This method can be done in any stage of the pregnancy by using tens of electric labors (Rajesh and Ganesan, 2014). The recorded signal by the invasive method of a higher quality compared with non- invasive. However, this procedure sometimes not suitable to get The (ECG) and is used only to record during parturition. Generally speaking, lower SNR for FECG and interference as result of MECG, base line wonder, power line interference (PLI), random electric noise and EMG of wide frequency noise could be the conditions to reduce the use of non- invasive ECG (Rajesh and Ganesan, 2014). The electrocardiogram (ECG) could be the best choice to measure conductive signals of heart and can be obtained by putting electrodes on the mother venture. The basic components of ECG is a set of standard waves (P, Q, R, S and T). Fetal ECG permits to determine the fetal heart rate (FHR) and other features like the morphologic ones. One of the most important indicators that could give us an idea about the fetal heart activity is the relative amplitude and timing related to ECG signal like (P/R, Q/R, S/R, R-R interval and T/QRS ratio which gives us information about (FHR). T/QRS is useful to determine some cases like tachycardia (FHR>180 b.p.m) or branchy cardiac (FHR<110 b.p.m) (Comani et al., 2005). Obviously, ECG sounds very attractive to be used, but formerly the use of ECG in clinics was very limited because of the shortage in clinical technology in reading and displaying that signal. Besides, the FECG is an abdominal ECG that contains many interferences where as the recorded signal would be the mix of many signals due to the bioelectric phenomenon. This phenomenon is caused by breathing, stomach activity and muscles activity. The ECG also is affected by different types of noise like thermal noise, noise caused by electrode –skin contact, electronic noise and power line interference. The problem would be more complicated in twins case as they may have the same morphology, amplitude and FHR (Comon and Jutten, 2009). Generally the current methods that are used to observe fetal inside the intrauterine does not give a comprehensive evaluation to the fetal hygienic case. One of the most important indicator for the fetal status is the cardiac functions that reveal circumstances like cardiac hypertrophy heart defects and arrhythmia (Comon and Jutten, 2009). For single fetal pregnancy there are many algorithms used for extracting fetal ECG signal from the other signals. IIR adaptive filtering and adaptive filtering techniques such as last mean square (LMS) had been used (Xueyun and Wei, 2018; Kaleem and Kokate, 2019). Singular value decomposition has been used for extraction single fetal (ECG) as well (Zarzoso and Nandi, 1999).Wavelet transform also used to process ECG signals (Manjula, 2018). There are few studies that discuss the problem of twin gestation. For instance, Lathauwer discussed twin case "fetal electric cardiogram" extraction by blind source separation. He developed a method to separate both FECG and MECG (Lathauwer et al., 2000). Taylor also wrote a general clinical study on both single fetal and twin to record heart time periods in normal pregnancy (Taylor et al, 2003). A. Kam and A. Cohen discussed the problem of extracting twin fetus ECG in a published paper with title "SEPARATION OF TWINS FETAL ECG BY MEANS OF BLIND SOURCE SEPARATION (BSS), they used an adaptive filter to cancel the noise and then used the JADE algorithm to separate MECG, F1-ECG and F2-ECG (Kam and A. Cohen, 2000). Comani et al. and Burgoff et,al used the measured magneto cardiograph data of twin. They used ICA-TDSEP algorithm and 9 magnetos cardiograph. They proved that between 28th and 38th week twin fetal ECG could be separated from not only mother ECG but also the noise as well (Comani et al., 2005; Burghoff and Van Leeuwen, 2004). Malika kevalupura, Mehrded Pourfathi and Birsen Sirkeci Mergen wrote a paper under the title of "Impact of Contrast Functions in The ICA on Twin ECG Separation", they used fast ICA with multi and different contrast functions to separate twin fetal ECG from mother ECG. They depend on the performance index as criterion (Keralapura et al., 2011). M. kotas, J.M.LESKI and J.WKOBEL, They published research with title "Sequential Separation of Twin Pregnancy Electrocardiogram". In their research they used a new method of sequential determination of source sub spaces (SDSS) combined with ICA merged with either projective or adaptive filter to separate sources signal (Kotas et al., 2016). Salman Vardi M, and Z. Einalou also discussed the problem of extracting twin fetal ECG through their research under title "Separation of Twin Fetal ECG From Maternal ECG Using Empirical Mode Decomposition Techniques " They invented new method by combining principal component analyses (PCA), standard empirical mode decomposition (EMD) and ensemble empirical mode decomposition (EEMD) (Salmanvandi and Einalou, 2017). Rolant Gini J., Ramachandran K.I. and Ceerthibala U.K. wrote a research under the title "Approach to Extract Twin FECG for Different Cardiac Condition During Prenatal". They invented a new algorithm to detect the R - peak for each mother and fetuses (Ramachandran and Ceerthibala, 2017).

2. TEMPORAL PREDICTABILITY

Temporal predictability concept is used for describing the time period which separates a series of events. This period of time may be regular or irregular so when a repeated cases of cause and effect are faced, it face another multi temporal periods. If these periods are constant, then it is possible to predict the next event (Greville and Buehner, 2016).

2.1. STONE Blind Source Separation

Stone BSS technique exploits temporal predictability property to separate the mixed signals unlike other BSS technique that use different properties to implement separation (Abdullah and Zhu, 2014). Stone estimation depends on very simple principle which is that the temporal predictability must be equal or less than its components and this step helps to select every single weight for each vector to obtain orthogonal projection (Stone, 2002).

Just like the other BSS techniques Stone system starts with

$$Xk=ASk \qquad 1$$

Since the first equation represents the system without noise. X is the mixed signals, S is the sources matrix and A is the mixing matrix. Symbol K could be sample or time index. The aim of all the operations is to restore [S], which is the sources from [X], which is mixed signal without prior knowledge of [A] matrix. To get rid of this problem we need to find another matrix known as W which is equal to: W=A-1. Separation model has been established to calculate the record signal.

$$Y(k) = W\,X(k) \qquad 2$$

To get the scaling before S is going to be replaced with Y

$$F(y)=\log\frac{V_y}{U_y} = \log\frac{\sum_{k=1}^{N}\left(y_{long}(k)-y(k)\right)^2}{\sum_{k=1}^{N}\left(y_{short}(k)-y(k)\right)^2} \qquad 3$$

Equation 3 gives a definition to the temporal predictability measured by Stone.

$$yshort(k)=\beta S yshort(k-1)+(1-\beta S)y(k-1) \quad :0\leq\beta S\leq 1 \qquad 4$$

$$ylong(k)=\beta L yshort(k-1)+(1-\beta L)y(k-1) \quad :0\leq\beta L\leq 1 \qquad 5$$

N equal to number of sample proportion to Y(k), βL =2-1/h_{long}, βS =2-1/$h_{short}$where both hshort and hlong denote to half parameter life. Stone created relation between βS and βL. The relation is: half –life h long of βL is longer than half life h short of βS with 100 times (Stone, 2001).

By assuming y(k)= w_i^Tx(k), W=[w1,w2,w3,.....,wn].By substituting in equation 3 then we get

$$F(y_i) = \log\frac{w_i C_{xx}^{long} w_i^T}{w_i C_{xx}^{short} w_i^T} \qquad 6$$

C_{xx}^{long} and C_{xx}^{short} are respectively long and short term covariance matrix (NxN) of mixed signal.

$$C_{x_i x_j}^{short} = \sum_\tau \left(X_{i\tau} - X_{i\tau}^{short}\right)\left(X_{j\tau} - X_{j\tau}^{short}\right) \quad 7$$

$$C_{x_i x_j}^{long} = \sum_\tau \left(X_{i\tau} - X_{i\tau}^{long}\right)\left(X_{j\tau} - X_{j\tau}^{long}\right) \quad 8$$

Getting the un-mixing vector by maximizing Rayleigh quotient is the main concern of Stone BSS and here comes the need of using Eigen vectors of $C_{x_i x_j}^{long}$ $[C_{x_i x_j}^{short}]$-1 ,which represents orthogonal of the covariance matrices, to serve the previous purpose (Stone, 2004).

$$W_i C^{short} W_j^t = 0 \quad 9$$

$$W_i C^{long} W_j^t = 0 \quad 10$$

Where:

$$W_i C^{short} W_j^t = \sum_\tau \left(y_{i\tau} - y_{i\tau}^{short}\right)\left(y_{j\tau} - y_{j\tau}^{short}\right) \quad 11$$

$$W_i C^{long} W_j^t = \sum_\tau \left(y_{i\tau} - y_{i\tau}^{long}\right)\left(y_{j\tau} - y_{j\tau}^{long}\right) \quad 12$$

When hshort goes toward zero (hshort $\rightarrow$0) hence short term would be:

$$y_\tau^{short} \approx y_{\tau-1} \quad 13$$

$$\left(y_\tau - y_\tau^{short}\right) \approx d_{y_\tau}/d\tau = \acute{y}_\tau \quad 14$$

When hlong as well goes towards infinite (hlong $\rightarrow \infty$) and in case of y has zero mean, the long term mean would be

$$y_\tau^{long} \approx 0 \quad 15$$

$$\left(y_\tau - y_\tau^{long}\right) \approx y_\tau \quad 16$$

According to the above equations the expected value of both yi and yj would be equal to zeros.

$$E\left[y_i y_j\right] = 0 \quad 17$$

The previous equations proved that every single restored signal yi is calculated by yi=WiX is not correlated with the other mixed signals and could be used to show that all the components are independent and the anticipated value would be zero as well, Stone is very suitable method for linear mixture separation (Stone, 2001). The anticipated value is equal to zero because the temporal derivative of each restored single signal is uncorrelated with each other (Stone, 2001).

$$E[\acute{y}_i \acute{y}_j] = 0 \quad 18$$

Separating matrix could be obtained by using the mat lab program and specifically the Eigen value function (Stone, 2001).

$$W = \mathrm{eig}(C^{long} C^{short}) \quad 19$$

Stones BSS has many advantages; one of them is propagate Eigen problem (Ye and Li, 2007). Fig. 1 illustrate the general Stone algorithm block diagram.

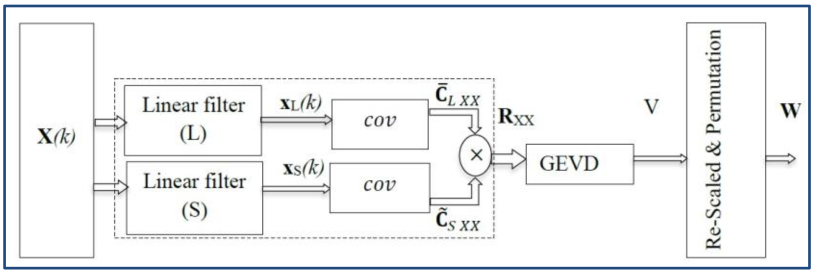


Fig. 1. Block diagram of STONE Blind Source Separation Algorithm.

Where:

X (k) = Mixture observation signals, XL (k) =Filter Response (L), XS (k) =Filter Response (S)

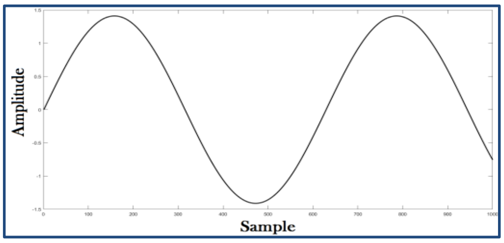
$\bar{\boldsymbol{C}}L\ XX$= Long-term covariance matrix, $\tilde{\boldsymbol{C}}S\ XX$ = Short-term covariance matrix, RXX = $\bar{\boldsymbol{C}}L\ XX\tilde{\boldsymbol{C}}S\ XX$

V= Eigenvector matrix RXXV=VD; W=Un-mixing matrix

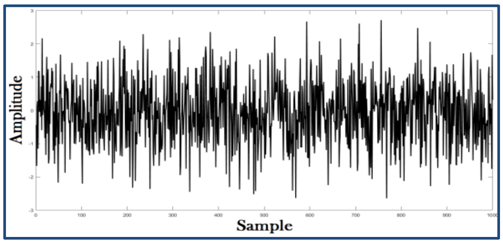
3. DATA SET

3.1. ABio 7 Database:

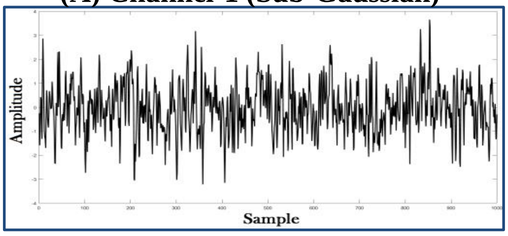
It is the criterion of ICALAB (Cichocki et al., 2004), the dataset consist of 7 channels, each channel contain one signal with sampling rate equal to 250 Hz. It also has zero mean, unity variance and 500 samples. Signal 1, 5 and 6 are Sub Gaussian while signal 4 and 7 are Super Gaussian and finally signal 2 and 3 are Gaussian. Below Fig. 2 demonstrates the shape of Abio-7 database signals.



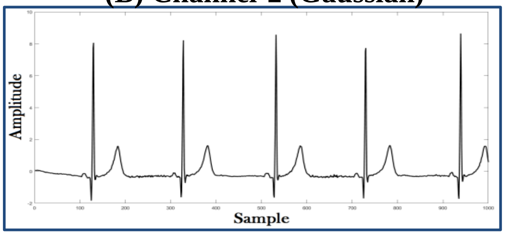
(A) Channel-1 (Sub-Gaussian)



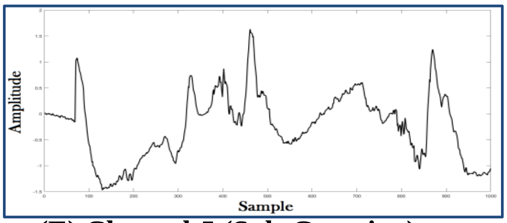
(B) Channel-2 (Gaussian)



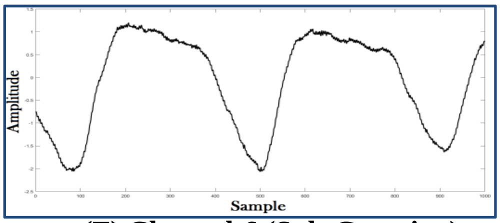
(C) Channel-3 (Gaussian)



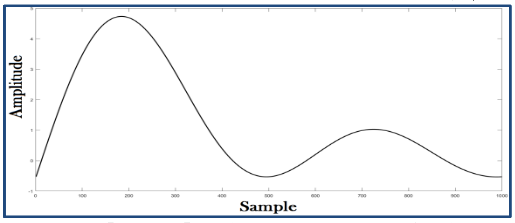
(D) Channel-4 (Supper-Gaussian)



(E) Channel-5 (Sub-Gaussian)



(F) Channel-6 (Sub-Gaussian)



(G) Channel-7 (Supper-Gaussian)

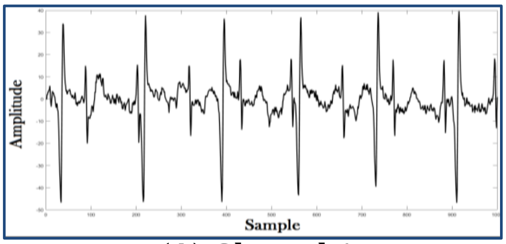
Fig. 2. The ABio 7 Database.

3.2. Real Data

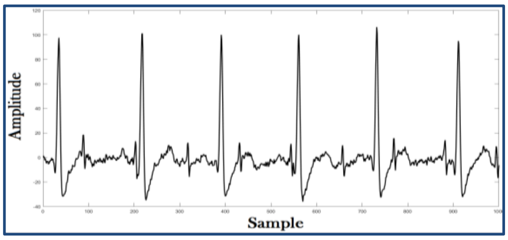
DaISy database has been used (Moor et al., 1997). The data is obtained by placing three electrodes (channels 6, 7 and 8) over the thorax area of the mother body and five electrodes (channel 1,2,3,4 and 5) on the abdomen. The signals are sampled at 250 Hz and the recording of signals last for 10 seconds. First mother and fetal signal are separated from the real signals of DaISy database by three different blind source separation algorithms. Fig. 3 The real in vivo data from the online DaISy database

3.3. Semi-Simulated Data

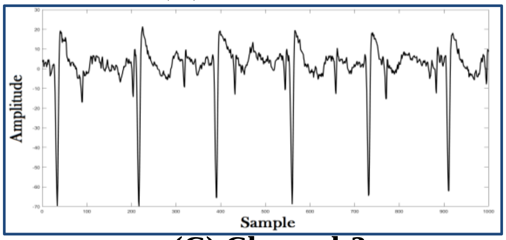
Until now there is no available recorded database online for twin gestation because it needs independent clinical study (Keralapura et al., 2011). Only single fetal pregnancy real database is available. For this reason and to keep all provided data for all algorithms real as can as possible, the extracted signal of fetal will be repeated and multiplied by factor to make a little change in the shape of the second fetal signal, and to represent the signal of the other fetal to satisfy the study of twin case gestation. That factor adds shift in to the fetal signal to simulate the real case of twin fetuses gestation.



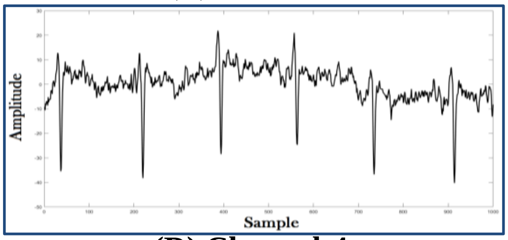
(A) Channel-1



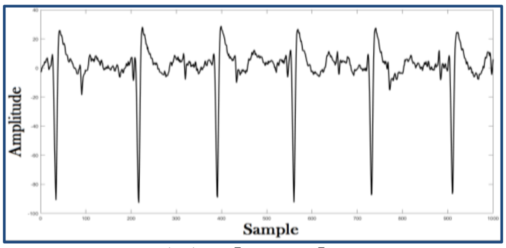
(B) Channel-2



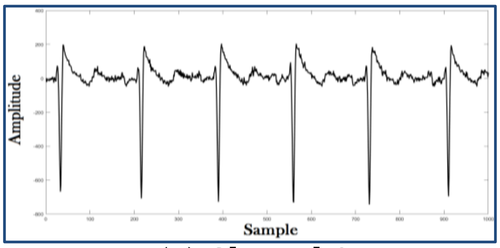
(C) Channel-3



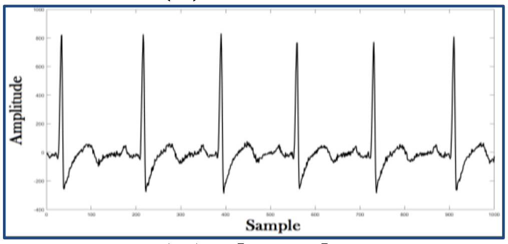
(D) Channel-4



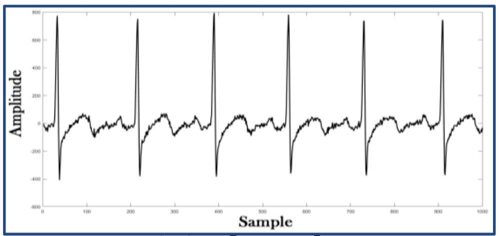
(E) Channel-5



(F) Channel-6



(G) Channel-7



(H) Channel-8

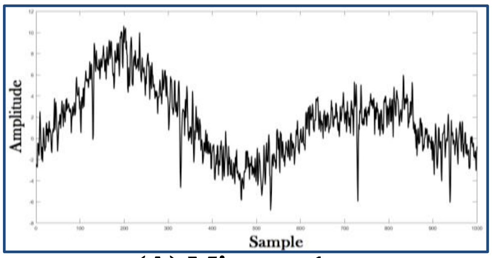
Fig. 3. The real obtained data from the online DaISy database.

4. RESULTS

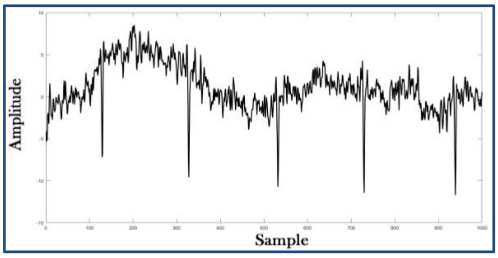
The reason of selecting Stone algorithm to extract the ECG signal is, Stone exploit the temporal predictability feature to process the signal. The ECG signal is a series of repeated QRS-waves in a specific time periods. This feature of ECG signal satisfy the concept of temporal predictability which is the principle of Stone algorithm operation.

4.1. CASE 1: The Abio-7 dataset

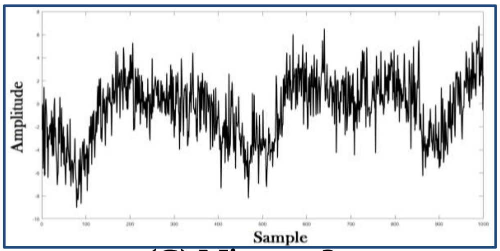
The Abio-7 dataset is used to test the performance of the three selected algorithms (STONE, EFICA and JADE). All the signals in the Abio-7 are mixed randomly together to produce the new input for the algorithms as shown in Fig. 4.



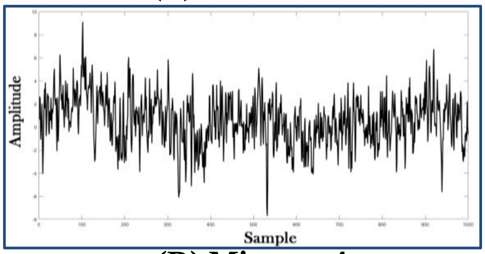
(A) Mixture-1



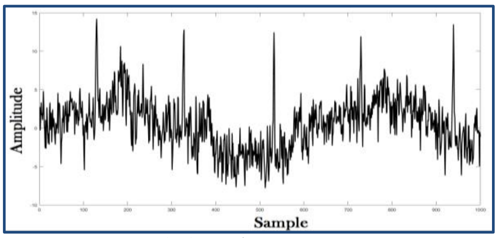
(B) Mixture-2



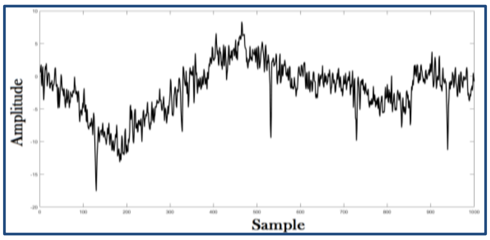
(C) Mixture-3



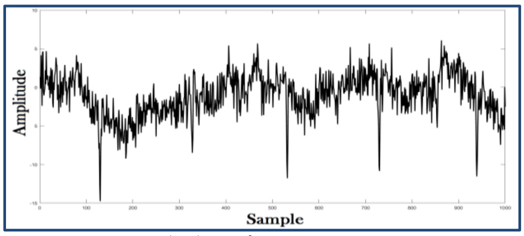
(D) Mixture-4



(E) Mixture-5



(F) Mixture-6

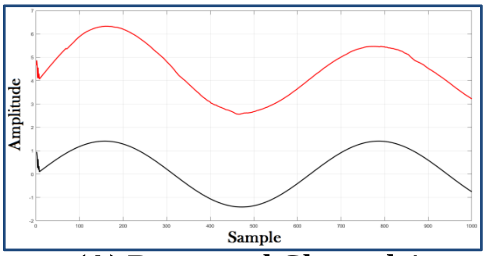


(G) Mixture-7

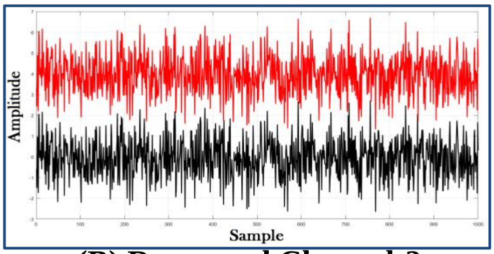
Fig. 4. The mixture of ABio-7 signals.

After all signals have been mixed, the mixture matrix is the input for the three algorithms (Stone, EFICA & JADE) so as get the final restored signals.

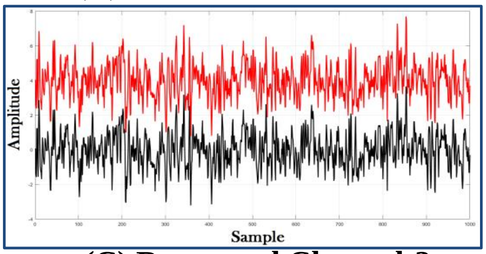
To verify which algorithm has the best performance we need to compare them depending on the achieved SNR. Table 1 represents a comparison between all algorithms depending on the obtained average signal to noise ratio (SNR) for each method. Fig. 5 shows the recovered signal after using Stone BSS algorithm to restore all signal sources.



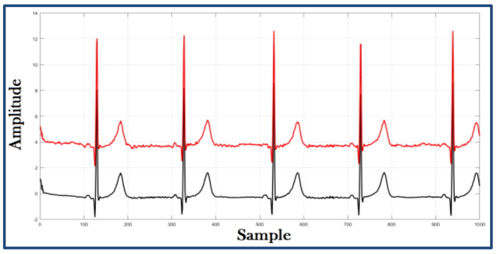
(A) Recovered Channel-1



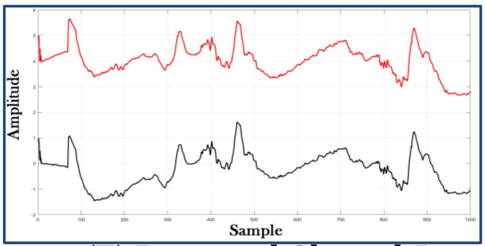
(B) Recovered Channel-2



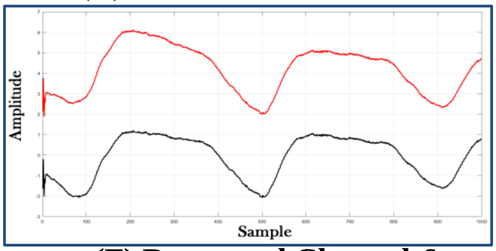
(C) Recovered Channel-3



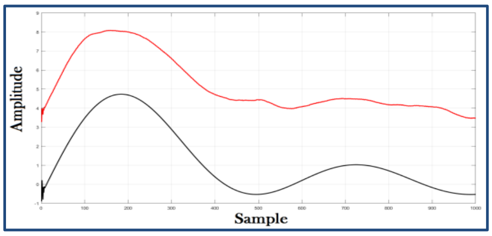
(D) Recovered Channel-4



(E) Recovered Channel-5



(F) Recovered Channel-6



(G) Recovered Channel-7

Fig. 5. The source and restored signals by Stone BBS algorithm.

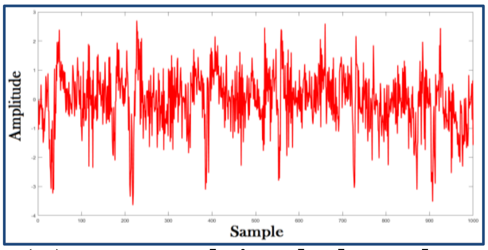
Table 1. The recorded average SNR for each single algorithm.

NO.	BSS Algorithm	Recorded Average SNR
1	STONE	16.88
2	EFICA	22.36
3	JADE	14.47

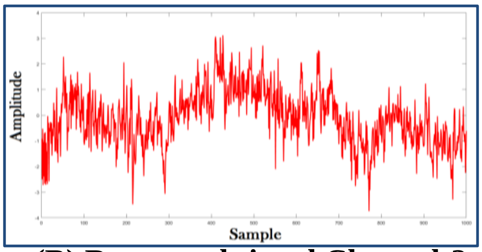
From Table 1, EFICA algorithms record the highest value of calculated SNR. STONE algorithm records less SNR than EFICA but is better than JADE algorithm. This supports what has been mentioned in Stone's paper where he states that his algorithm is not the best algorithm to restore the (Gaussion, Sub-Gaussion and Super-Gaussion) signals (Stone, 2002).

4.2. CASE 2: Single Pregnancy

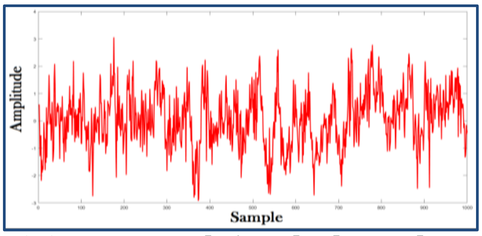
In this part, the extraction of both mother and single fetal ECG signal will be discussed depending on the output of the three algorithms. The eight channels of the DaISy dataset, which is illustrated previously in Fig. 3, are the input for each BSS algorithm (STONE, EFICA & JADE). Fig. 6 shows the extracted signals by Stone BSS algorithm.



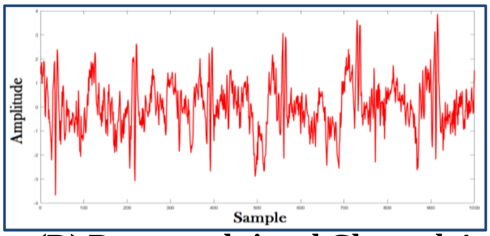
(A) Recovered signal Channel-1



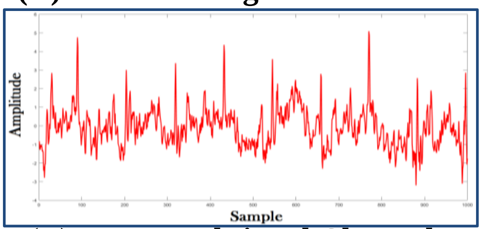
(B) Recovered signal Channel-2



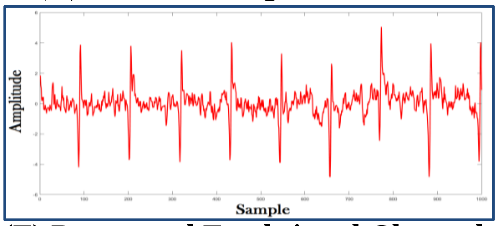
(C) Recovered signal Channel-3



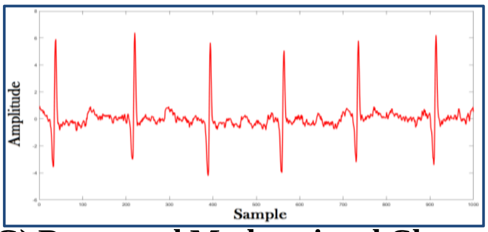
(D) Recovered signal Channel-4



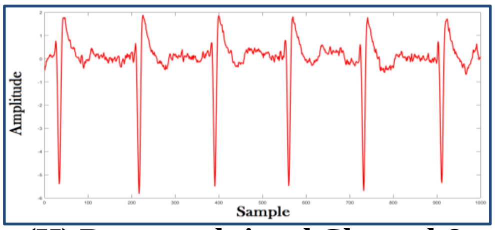
(E) Recovered signal Channel-5



(F) Recovered Fetal signal Channel-6



(G) Recovered Mother signal Channel-7



(H) Recovered signal Channel-8

Fig. 6. The extracted signals by STONE BBS algorithm.

However using the visual inspection, it very obvious that the noise has less effect on the extracted signals by STONE BSS algorithm. From the extracted signal for the mother and fetal it is so easy to calculate the fetal heart rate (FHR) which equal to (132 bpm) and mother heart rate (MHR) which is equal to (84 bpm). By focusing on small part of each extracted signal of fetal ECG and mother ECG and specifically the QRS- Complex, the impact of noise appears more clearly as shown in the Figs. 7, 8 and 9.

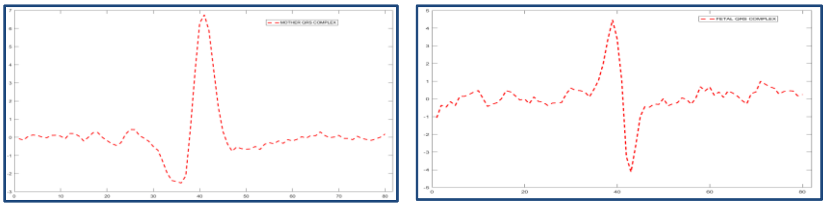


Fig. 7. The QRS complex for fetal and mother ECG after STONE BSS.

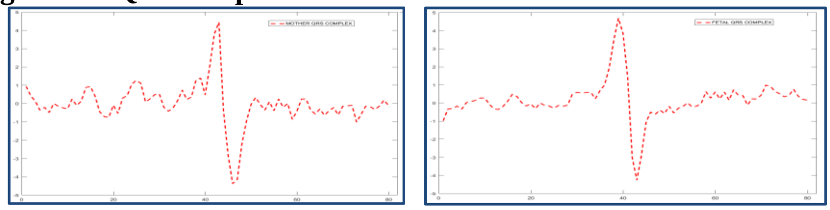


Fig. 8 The QRS complex for fetal and mother ECG after EFICA BSS

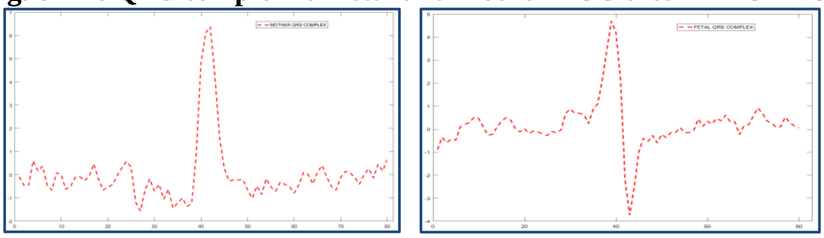


Fig. 9 The QRS complex for fetal and mother ECG after JADE BSS

For more clarification, the down Table 2 has been made to compare all restored signals (FECG & MECG) depending on the calculated power spectral density (PDS). Figs. 10 and 11 demonstrate the obtained PSD for mother and fetal ECG signal.

Table 2. The recorded PSD for each signal.

NO.	Signal	Real signal	After STONE	After EFICA	After JADE
1	FECG	101.3480	0.8340	0.8727	0.8623
2	MECG	101.3480	1.1098	1.0409	1.0289

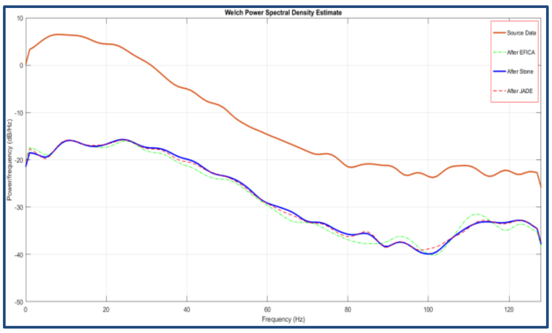


Fig. 10. The PSD for fetal ECG.

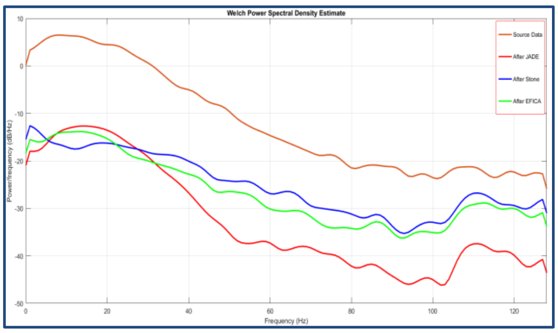


Fig. 11. The PSD for mother ECG.

4.3. CASE 3: Twin Pregnancy Simulation

As it has been mentioned previously in the simulated dataset part, one of the BSS algorithms out will be allowed to be the input to simulate the twin gestation case after doubling the signal of fetal. Three different noises, which have the biggest impact on the ECG signal extraction, are also added to be mixed with MECG, F1-ECG and F2-ECG. The extracted fetal and mother signal by Stone BSS in Case 2 will be depended to simulate twin gestation case. Fig. 12 below represents the input signals to simulate the twin case gestation.

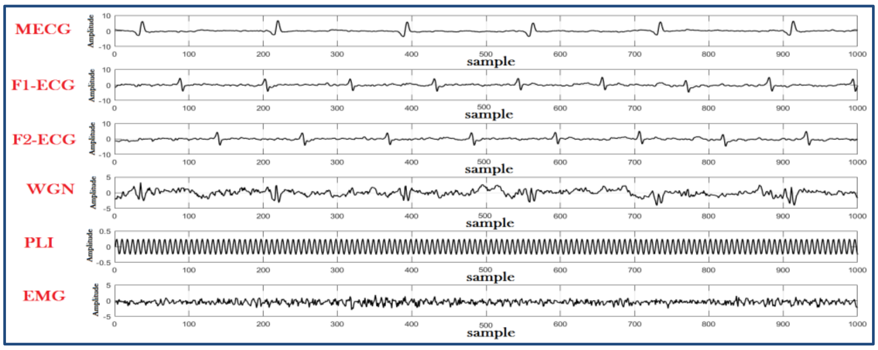
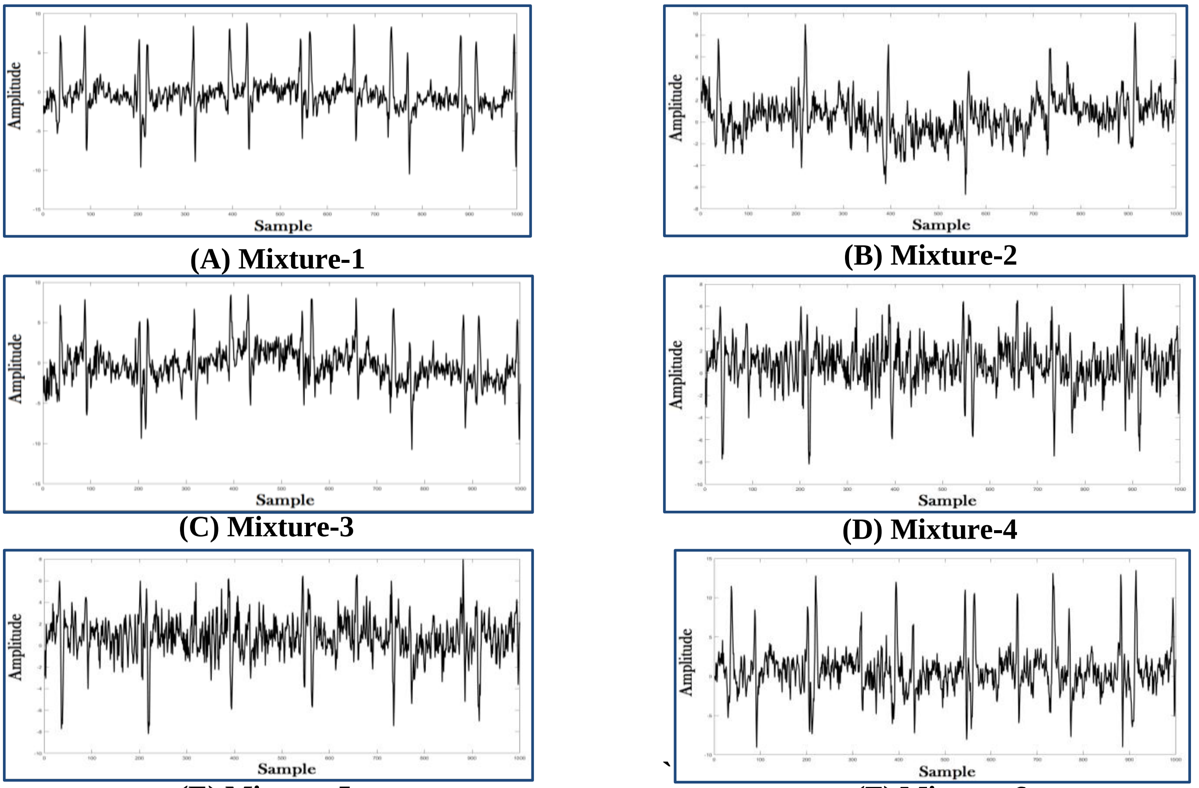


Fig. 12. The input signals to simulate twin case gestation.

After all input signals have been determine, signals are randomly mixed together to get the mixture matrix. Fig.13 illustrates the shape of signals after being mixed randomly by the mixing matrix while Fig. 14 shows the source and recovered signals by Stone BSS algorithm.

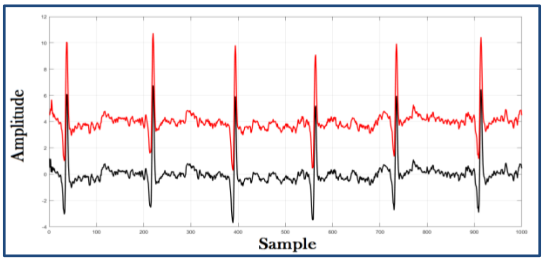


(A) Mixture-1 **(B) Mixture-2**

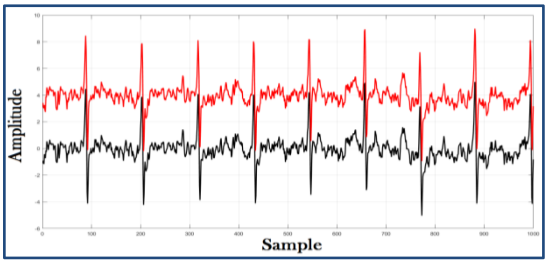
(C) Mixture-3 **(D) Mixture-4**

(E) Mixture-5 **(F) Mixture-6**

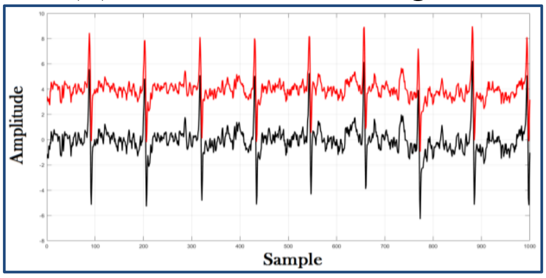
Fig. 13. The mixed signals to simulate twin case gestation.



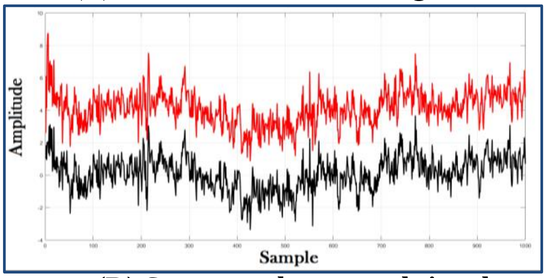
(A) Source and extracted signal



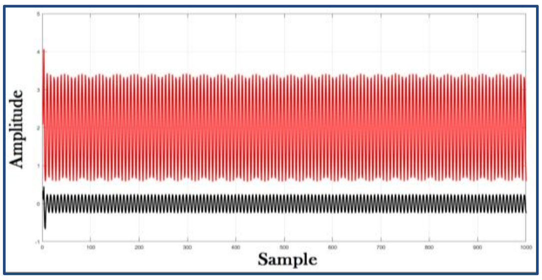
(B) Source and extracted signal



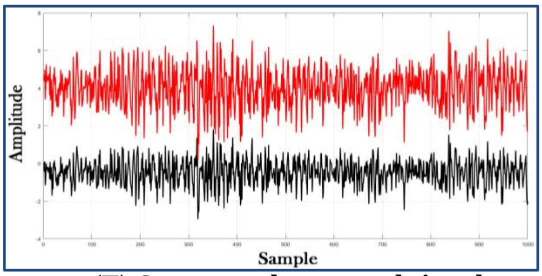
(C) Source and extracted signal



(D) Source and extracted signal



(E) Source and extracted signal



(F) Source and extracted signal

Fig. 14. The source and restored signals by Stone BBS algorithm.

The red signal represents the recovered signal after using BSS technique while the black signal is the original signal. The above figures do not give an idea about the best BSS algorithm in the extraction of signals whereas all algorithms restore the signals perfectly. To verify the best algorithm, all registered SNR for (MECG, F1-ECG & F2-ECG) are compared in Table 3. Table 3 proves that STONE BSS algorithm record the highest value of SNR comparing to the other BSS algorithms. STONE BSS has a better performance to restore and solve the problem of twin gestation than the EFICA and JADE BSS techniques.

Table 4 demonstrates the fitness between the restored signal and the original signal. STONE algorithm registers the highest value as well.

Table 3. The recorded SNR for each signal after each BSS algorithm.

NO.	Signal	STONE	EFICA	JADE
1	MECG	16.0870	13.4229	14.0289
2	F1-ECG	26.1084	20.3604	21.6098
3	F2-ECG	13.7739	13.2550	13.3065

Table 4. The percentage of correlation between recovered and original signals.

NO.	Signal	STONE	EFICA	JADE
1	MECG	98.77 %	89.55 %	90.4 %
2	F1-ECG	99.55 %	97.73 %	98.09 %
3	F2-ECG	95.92 %	88.59 %	89.62 %

5. CONCLUSIONS

In this paper and for the first time Stone's BSS algorithm has been used to process the problem of extracting single fetal ECG signal from abdominal ECG. Stone algorithm also used for the first time to deal with the problem of extracting the ECG signal for twin fetuses. The real data embedded with several types of interference has been used to in case of single pregnancy. Stone BSS algorithm shows better performance than the other algorithms to treat and extract single fetal pregnancy. From the results the Stone algorithm has the best performance as compared with other BSS techniques of extracting fetus's signals in twin case pregnancy simulation, maternal ECG and also to recover all sources of signals. Making modification to Stone algorithm to enhance the obtained results is possible. Combining Stone with any other optimization technique will improve its ability of separation.

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