BLIND SEPARATION OF ELECTROCARDIOGRAM INTERFERENCE FROM BOWEL MYOELECTRICAL SURFACE RECORDING

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Abstract: The myoelectric signal of the small intestine is known as electroenterogram (EEnG). The EEnG is the result of slow wave (SW) and spike bursts (SB). The SB represent the intestinal motility, whereas SW sets contractions rhythm. Clinical application of this technique is limited due to its invasiveness, surface recording could be a solution for monitoring the intestinal motility. Nevertheless, the surface recorded signals are contaminated by electrocardiagram interference (ECG). The ECG overlaps with the SB in frequency domain, thus it can not be eliminated by conventional filters. The goal of this study is to extract the ECG activity from surface recording of EEnG by means of blind source separation (BSS). Five recordings in bowel serosa and on abdominal surface of three Beagle dogs were carried out simultaneously in fast state. The correlation coefficient function (CCF) of energy over 2 Hz (EF2) between surface recordings and internal recordings is used as quality measurement of the method. The coeficient correlation for the original recordings is 0,57±0,06, and the coeficient after the application of BSS is 0,61±0,08. The results show that ECG activity on surface recording EEnG can be extracted by BSS method, and the non-invasive intestinal motility index are improved.

Keywords **– Electroenterogram, surface recording, intestinal motility, blind source separation.**

Introduction

It is well known that myoelectric signal recorded from small bowel serosa (EEnG) is associated with intestinal mechanical contraction [3]. The EEnG is the result of slow wave (SW) and spike bursts (SB) (Fig. 1a). The former is always present, it does not represent intestinal motility but the maximum rhythm of small bowel contractions. The latter appears when the smooth muscle contracts and indicates moving activity.

When a fast state of more than 8 hours is being held, the electroenterogram follows a pattern of activity called interdigestive migrating myoelectric complex (IMMC). IMMC is divided into three phases. Phase I presents minimum contractile activity, the ratio of slow wave accompanied by a SB is less than 10% during this periode. In phase II this ratio has to be higher than 10% and not greater than 90%. In phase III more than 90% of SW have an associated SB and it is the phase with maximum mechanical activity.

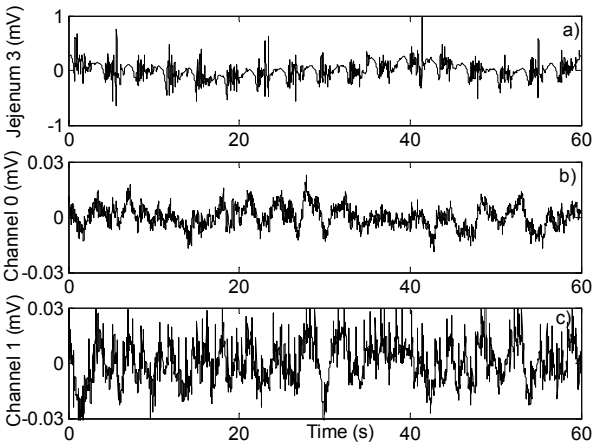

Fig 1. One minute of myoelectric signal recorded simultaneously form internal and external electrodes in phase III. a) Internal signal: jejunum 3. b) External signal: Channel 0. c) External signal: Channel 1.

However, the application of myoelectric techniques for clinical diagnostic purposes is restraint because surgery is required. Surface recording could be an alternative for monitoring intestinal motility noninvasively. Energy over 2 Hz of external signals has been proved to strongly correlate with intestine mechanical contraction [4]. Fig. 1 shows one minute of myoelectric signal recorded simultaneously from internal and external electrodes in phase III.

Surface EEnG recordings have been performed with only one channel recorded and analyzed. Due to the poor quality of the recording, i.e, the weakness of the real myoelectrical signal and the strong interference such as respiratory artifact, ECG (Fig. 1b and 1c) and random noise, multichannel EEnG is required. The ECG interference can be eliminated by conventional low pass filters, but it will remove also the SB. This is because the ECG overlaps with the SB in frequency domain. Thus conventional filters are not recomended to eliminate ECG interference.

ISSN: 1727-1983

Recently, blind source separation has found promising applications in biomedical signal ([1], [2], [5], [8]). It was developed for the separation of signal components that are statiscally independent. This is very suitable for the separation of the ECG activity from the surface intestinal signals where they are statistically independent. Furthermore, it can not be known how they are mixed in time domain.

This paper focus on the extraction of ECG interference from surface recording of EEnG by means of Blind Source Separation (BSS). Experiments were conducted to validate the proposed method.

Materials and methods

Surgical intervention was carrried out to implant six bipolar Ag-AgCl electrodes along small bowel serosa of the dog. Internal electrodes were placed in the duodenum, Treitz angle, ileum, and the other three electrodes were distributed along the jejunum. One internal electrode (jejunum 3) was sutured to internal abdominal wall in order to have a reference position for three sessions.

External signals were recorded by two bipolar Ag-AgCl electrodes with an inter-electrode distance of 2 cm and positioned on the abdominal skin.

Five recording sessions were conducted with three Beagle dogs in fast state for more than 12 hours. Each session implied the recording of more than 150 minutes of biosignals: 2 externals, channel 0 and 1, and 6 internals. Figure 1 shows 1 minute of surface recordings and internal recording simultaneously in phase III.

All 8 signals were amplified and band-pass filtered with a bandwith of [0.05 Hz, 35 Hz]. Signals were acquired with a sample rate of 100 Hz and subsequently analised under Matlab developed software.

The two surface recorded biosignals were processed by BSS method. Blind source separation consists in recovering a set of statistically independent signals whose only mixtures are observed. Such instataneous mixtures occur in narrow band array data which can then be processed without knowing the array manifold (blindness).

It was assumed that the source signals are second order stationary, mutually uncorrelated processed, and can be myoelectric signal of the small intestine, ECG activity, etc. The mixture of the sources of the sensor output x(t), surface recording of EEnG in this case, can be described by

$$x(t) = y(t) + n(t) = As(t) + n(t) \qquad (1)$$

where $A \in \Re^{mxn}$ is an unknown mixing matrix, $x(t)=[x_1(t),...,x_m(t)]^T$ is the noisy intantaneous linear mixture of souce signals. In this context, vector $s(t)=[s_1(t),...,s_n(t)]^T$ contains the signals emitted by n narrow band sources, vector $y(t)=[y_1(t),...,y_n(t)]^T$ is the noiseless mixed signals. The additive noise n(t) is modeled as a stationary, temporrally white, zero-mean complex random process independent of the source signals. For simplicity, the *mxn* matrix A is assumed to have full column rank but is otherwise unknown.

Without knowing the source signals and the mixing matrix, one intends to recover the original signals from the observations x(t) . In this paper, second order blind identification (SOBI) algorithm developed in [6] was applied. The unmixing matrix learning algorithm can then be summarized in Table 1. The parameter τ used in this paper is 5.

Table 1: SOBI algorithm implementation

1. Estimate the sample covariance matrix $\hat{R}(0)$ from T data. The covariance matrix is obtained by this form: $R(0) = E\{x(t)x^*(t)\} = AR_s(0)A^H + \sigma^2 I$.
2. Whitening the signal parte y(t) of the observation. The whitened signals z(t)=Wy(t) should verify that $E\{Wy(t)y(t)^* W^H\} = WR(0)W^H = I$.
3. Form sample estimates $\underline{\hat{R}}(\tau)$ by computing the sample covariance matrices of z(t) for a fixed set of time lags $\tau \in \{\tau_j | j = 1,...K\}$. It should be note that $R(\tau) = E\{x(t+\tau)x^*(t)\} = AR_s(\tau)A^H, \quad \tau \neq 0.$
4. A unitary matrix $\hat{U}$ is then obtained as joint diagonalizer of the set $\{\underline{\hat{R}}(\tau_j) | j = 1,...K\}$
5. The source signals are estimated as $\hat{s}(t) = \hat{U}^H \hat{W} x(t)$.

In order to quantify the quality of the proposed method, myoelectric signals are analised in spectral domain. This is because frequency content of electroenterogram has been proved to be fundamental for quantifying the intensity of the bowel motility [3]. Hamming modified periodograms were calculated from surface EEnG considering 1 minute length of biosignals. In order to obtain IMI from each of the six internal signals, energy in spectral domain is calculated without considering SW of the electroenterogram (EF2) [3].

The BSS method has the permutation and scale problem. In the present study, a correlation analysis in time domain allows to solve the permutation problem. The scale problem was solved considering that the energy associated to SW (Esw) remains constant in the BSS processing. Let $\hat{s}_1(t)$ be the estimated noise free biosignal after the application of BSS method, and $x_1(t)$ is the original surface recording, therefore scaled EF2 of the noise-free biosignal was processed according to the equation (2):

$$EF2_{\hat{s}_1(t)}(\text{scaled}) = \frac{EF2_{\hat{s}_1(t)}(\text{no scaled}) \cdot Esw_{x_1(t)}}{Esw_{\hat{s}_1(t)}} \qquad (2)$$

where $Esw_{\hat{s}_1(t)}$ is the energy associated to SW of $\hat{s}_1(t)$, whereas $Esw_{x_1(t)}$ is the energy associated to SW of $x_1(t)$.

ISSN: 1727-1983

Finally, the correlation coefficient function (CCF) of EF2 between surface recordings and internal recordings is used as quality measurement of the method. Every CCF is defined by its maximum value and its corresponding time lag.

Results

Fig. 2 shows 15 seconds of surface recordings before and after the application of the BSS. It can be observed that the original surface recording (Fig. 2a and 2b) is contaminated by the ECG interference. The application of BSS method can only extract one noise free biosignal (Fig. 2d), whereas the ECG interference is concentrated on the other output (Fig. 2c).

The correlation analysis in time domain allows to know that the noise free biosignal correlate strongly with original channel 0. Frequency domain analysis allows to quantify the elimination of ECG interference. Fig. 3 shows the Hamming periodogram normalized to the energy of slow wave (Esw) associated to the biosignal of Figure 2. It can be observed that the EF2 of the noise-free biosignal is smaller than the EF2 of Channel 0.

Fig. 4 shows EF2 of internal recordings and EF2 of surface recording. Synchronization of interdigestive migrating myoelecric complex (IMMC) was detected on abdominal surface (see Fig.4b) and internal recording (see Fig. 4a). It was observed that the EF2 of the noise-free biosignal (see Fig. 4c) is smaller than original surface recording along the session (see Fig. 4b). Therefore, the IMI can be redefined improving results compared to others authors [4].

Correlation analysis of EF2 between surface and internal recordings was carried out. The coeficient correlation for the original recordings is 0,57±0,06, and the coeficient correlation after the application of BSS is 0,61±0,08. The results show that the BSS improves the correlation coefficient of EF2 (see Table 2).

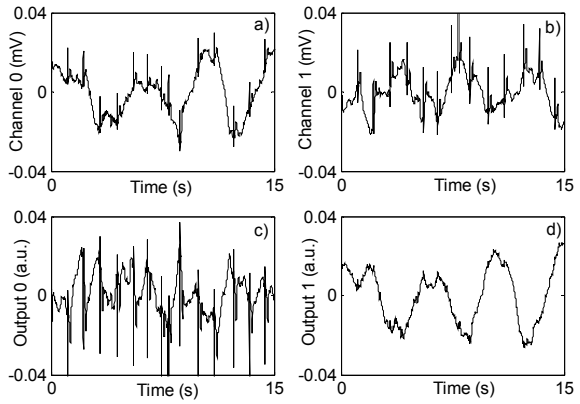

Fig. 2. Fifteen seconds of external signals recorded from Beagle dogs before and after the application of BSS method. a) Original surface recording (channel 0). b) Original surface recording (channel 1); c) and d) outputs of the BSS method. It can be observed that the ECG interference is concentrated in the output 0 in this case, whereas output 1 is the noise-free biosignal. The scale factor is 0.76 for this minute.

The effectiveness of the method depends on the ECG contamination of the original recording, and it can not be compared among sessions.

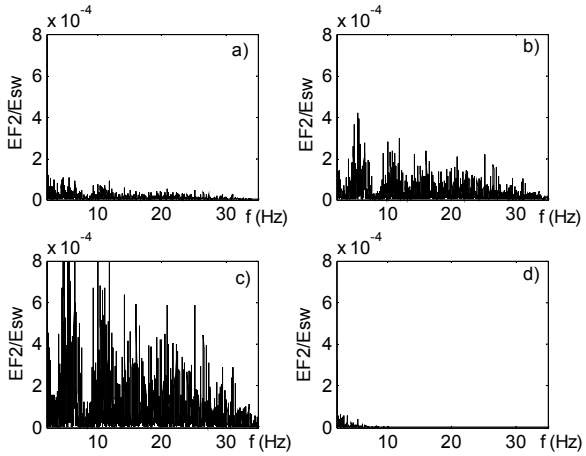

Fig. 3. Hamming periodogram in [2, 35] Hz normalized to Esw of the biosignal shown in Fig. 2. a) Original surface recording (channel 0). b) Original surface recording (channel 1); c) and d) outputs of the BSS method.

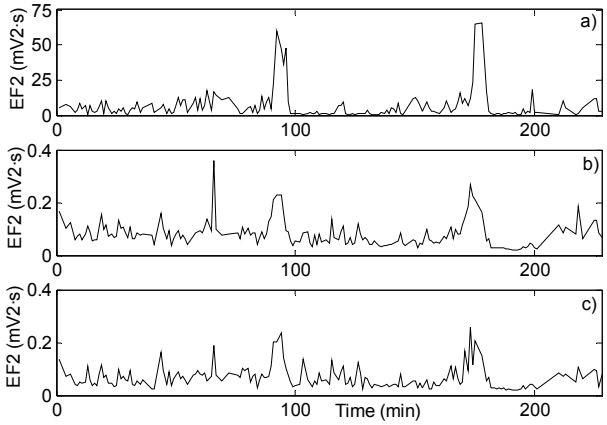

Fig. 4. Intestinal motility index of session 1. a) Internal reference recording. b) Original surface recording (channel 0). c) Noise-free biosignal extracted by means of BSS method.

Table 2: Maximum value of the correlation coefficient function of EF2 between surface and internal recording before and after the application of the BSS. N is nº of minute used to obtain the CCF. Lag is the time lag used to obtain the maximum of CCF.

Session	N	Lag (min)	Original channel 0	Original channel 1	Noise-free biosignal
1	179	0	0,55	0,27	0,59
2	150	0	0,58	0,24	0,60
3	128	0	0,66	0,18	0,74
4	157	0	0,51	0,43	0,54
5	193	-7	0,56	0,35	0,57
Mean±sd	5		0,57±0,06		0,61±0,08

ISSN: 1727-1983

Discussion

EEnG surface recording is very attractive since it is non-invasive. One of the main problems with the surface EEnG is the poor quality of the recording, i.e., the weakness of the intestinal signal and the strong interference such as ECG, respiratory and motion artifacts. As a result, direct visual analysis is impossible.

The ECG interference can be eliminated by conventional low pass filters, but it removes also the SB. This is because that the ECG overlaps with the SB in frequency domain. Thus conventional filters are not sufficient to eliminate ECG interference.

Other authors defend the elimination of ECG interference from electrogastrogram by the QRS deteccion algorithm [9],[10]. Then they replace them for linear ones, and a further application pass band filters. However, these cutaneous electrogastrogram only detect SW that does not traduce gastric motility.

Recently, blind source separation has found promising applications in biomedical signal. The main advantadge of BSS method is that no prior knowledge on the structure of sources is needed. The BSS method is capable to extract the muscle activitity, ocular activity, the ECG activity from the EEG signals [2]. The BSS method could also be used to extract the respiratory artifact from cutaneous EGG [8].

In this paper, it was shown that BSS method allows to extract one noise free biosignal, whereas the ECG interference is concentrated on the other output. This result is in agreement with others authors who show that the gastric slow wave can be recovered from three cutaneous EGG recording [8], whereas the respiratoy artefact is concentrated on the others outputs after the application of BSS method. They also show that this is possible due to that there are not sufficient recorded channels to extract completely the interference.

It was observed that BSS method has the permutation and scale problem (see Fig. 2). This result is in agreement with other authors [6],[7], who defend that a full identification of the mixture matrix **A** is impossible in the blind context. This is because the exchange of a fixed scalar factor between a given source signal and the corresponding column of **A** does not affect the observations. In this paper, a correlation analysis in time domain was used to solve the permutation problem, whereas the scale problem was solved by the equation (2).

The mean of the coefficient correlation function before and after the application of BSS method does not have significant difference. This is posible due to that the ECG interference is present and is almost constant throughout the session.

In present study, it was assumed that the signals are stationary in 1-minute window analysis. However, it has been shown in [11] that during irregular contractile activity, EEnG is a non-stationary signal if 1-minute length is chosen for its analysis. Therefore it is very atractive considering the non-stationarity of the signal in the BSS method.

Conclusion

The experimental results show that ECG interference on surface recording EEnG can be extracted by means of BSS method, and the IMI of surface recording can be improved. This can be very helpful in order to represent non-invasive intestinal motility.

The BSS method allows to obtain the statiscally independent sources, create a new line to eliminate the ECG interference from electroenterogram.

Acknowledgment

Preoperative, surgical and postoperative interventions, as well as the recording sessions, were carried out in the Veterinarian Unit of the Research Centre of the "La Fe" University Hospital in Valencia (Spain), assisted by C. Vila, PhD. This work was supported by a grant from the Ministerio de Sanidad y Consumo (FIS PI03/0432).

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ISSN: 1727-1983