OPTIMAL LOCALIZATION OF LEADS IN ATRIAL FIBRILLATION EPISODES

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ABSTRACT

To extract the Atrial Activity (AA) from the Ventricular Activity (VA) in Atrial Fibrillation (AF) episodes is a must for clinical analysis. We present a methodology to achieve this goal minimizing the number of leads and optimizing its localization starting from a Body Surface Potential Mapping (BSPM) recording. We present the acquisition system and the methodology, which consists on: apply Independent Component Analysis (ICA) to obtain a statistically independent representation of the data, apply the prior about the AA to identify it, and to find the contributions of each lead to the AA, obtaining finally the optimal leads necessary for the extraction. Following this procedure, we show that with only two leads the AA and VA can be recovered, so this technique is a very promising one in order to long term ECG recordings where the number of leads must be reduced. In addition, this procedure can be extended to other ECG-based problems where the ICA assumptions are satisfied.

1. INTRODUCTION

BSPM is an advanced electrocardiographic technique that, thanks to the use of a very high number of electrodes compared to standard 12-lead ECG, obtains a cardiac electric field map of the thoracic surface; see for example [1] and [2]. Although this technique was developed a few decades ago, its present use is still restricted to research laboratories.

Atrial fibrillation (AF) is a kind of tachycardia. A normal, steady heart rhythm typically beats 60-80 times a minute. In cases of AF, the rate of atrial impulses can range from 300-600 beats per minute. These very fast, irregular signals can cause a number of problems. First, the quivering atria no longer pump efficiently, and some blood may stay in the atria with each heartbeat. The pooled blood could possibly clot, increasing the risk of stroke. Second, the many impulses coming from the atria are trying to follow the electrical pathway to the ventricles and make them contract at the same rate. Luckily, the AV node limits the number of signals that actually reach the lower chambers, so the whole heart usually does not contract at the 300 bpm rate. However, AF can cause your heart to race and does reduce the pumping efficiency. The proper analysis of AF requires the extraction of the AA from the recordings, i.e., the cancellation of the VA.

In our application, BSPM will be used as a preprocessing tool to determine the minimum number of leads necessary to extract the AA from atrial fibrillation patients and its optimal position on the thoracic surface.

In the past, different research groups applied BSPM in the study of some cardiac diseases with different rates of success [3], [4]. In most of their studies some improvement in diagnosis was shown, but it didn't justify the application of such a laborious method. The number of electrodes used is variable between 32 and about 200. Recording positions are not defined and each research group has developed its own configuration. Undoubtedly, the number of acquired signals is higher than that recorded in traditional electrocardiograhpy so it collects a great amount of information that can be used to improve the results [5].

In summary, although the BSPM technique was developed some decades ago, much work has to be done in order that BSPM can become a practical clinical tool. At the time of its appearance recording such a big amount of electrocardiographic signals was so laborious because of technological limitations. Today the BSPM problem is up-to-date again: technology is not a limiting factor so that it is possible to take BSPM up again not just as a technique with a great potential for diagnosis but also to learn more about cardiac electrical activity itself by obtaining BSPM maps. Although its use in regular recordings is far away of being widespread, it is a promising technique to be used for preprocessing tasks as ours.

2. BSPM ACQUISITION SYSTEM

There are not only few commercial systems which implement any kind of BSPM systems, but they don't allow users to make any change and their cost is excessive for most research groups. Furthermore, standards for questions such as electrode arrangement, sampling parameters or display formats do not exist and taking one configuration as the definitive one can be risky because it can become obsolete if a definitive standard appears. In this work, a

low-cost opened system for the acquisition of BSPM maps was used. This system may be suitable for research works because of its good performance and flexibility. We departed from a commercial system for the recording of electrocardiographic signals: the Active One of Biosemi [6]. This is a multichannel recording system designed for biopotencial measurements and not specific for the acquisition of electrocardiographic signals. Consequently, there are many questions that have to be solved before one can use it to obtain satisfactory recordings. One advantage of using this system is that one can place the electrodes wherever wanted. But the main advantage is that it allows the storing of the signals in a standard format to be processed afterwards with a computer, so one can perform any kind of measurement, filtering or mapping technique.

The Active One that we own basically consists of a 66 active electrodes array and a 64-channel digital converter which permits the acquisition of up to 64 signals. Signals recorded are just potential differences between any surface point and a single reference point on the skin surface. A gel cavity has been specially designed to reduce motion artifacts, so that electrode gel has to be used for a better quality in the recordings. Biosemi supplies an adhesive electrode gel which is good for BSPM recordings because it improves the contact.

The A/D block firstly amplifies the 64 signals with a fixed gain and then samples them at a 2048 Hz rate, 16 bits per sample and a quantization resolution of 1 μV/bit. The system has a total bandwidth range (3 dB) from DC to 500 Hz, which is enough for ECG measurements.

The digitalized signals are then acquired in a host computer using a data acquisition card (National Instruments PCI-DIO-32HS). One can observe the signals and store them by means of an application provided by Biosemi which runs under Labview (National Instruments). The 64 simultaneous signals are then stored in the standard EDF file format for its posterior processing. In Fig.1 we can see the full system and the vest.

Figure 1: the full system (left) and front view of vest (right)

3. ANALYSIS OF BSPM ATRIAL FIBRILLATION EPISODES

The aim is to analyze the BSPM recordings to find out the AA and its spatial distribution over the thorax in order to future measurements and clinical studies. First, due to the fact that AA and VA are decoupled [7], a method to decompose the different activities in the BSPM recording is used. We apply ICA for this purpose. Second, a search in the subspace of possible AA is carried out to select the correct one. Third, the contribution of each lead in this component is studied in order to detect automatically the leads with highest AA. Four, these leads are selected to perform the ICA on this reduced dimension problem in order to detect the minimum number of leads necessary to extract the AA and its best location.

This approach has at least two advantages, depending on the application. On the one hand, for future clinical analysis of the AA, the BSPM recording allows a better extraction of the AA than the 12-lead traditional ECG, thanks to its higher dimensionality. On the other hand, for long-term recordings of ECGs, the BSPM recording allows to reduce the number of leads required to obtain the AA, and what it is more important, the optimal localization. In this paper, we focus in this second application.

3.1. BSS-ICA separation of the AA and VA

Blind source separation (BSS) consists in recovering the original independent sources of a mixed random vector without knowing the mixing structure [8]. The noiseless instantaneous mixture model reads:

$$\mathbf{x} = \mathbf{A}\mathbf{s} \tag{1}$$

where $\mathbf{x}$ is the mixed vector, $\mathbf{A}$ the mixing matrix and $\mathbf{s}$ the sources. In AF episodes, the VA and AA are the statistically independent sources [9], in addition to artifacts and noise signals.

First ICA algorithms differ in the way that they approximate the independence condition. All of them were based on the use of higher order statistics, in an explicit, e.g, higher order statistics, or implicit way, e.g., using non linear functions. This is the reason because at most only one Gaussian source is allowed in traditional ICA. In our case, a prior knowledge about the distribution of the sources is available. The VA and AA correspond to supergaussian and subgaussian random variables, respectively. The density of the AA usually varies between a Gaussian and a uniform r.v., i.e., for normalized r.v., kurtosis ranges from -1.2 to 0. In 64-lead BSPM recordings, our experiments show that the subspace of AA is usually composed of one up to three components, so for the patients where the AA is Gaussian, these statistical ICA algorithms fail because of the presence of more than one Gaussian signal, yet not considering the

distribution of noise. In addition, the ECG recordings have a time structure that traditional ICA algorithms do not exploit. For these reasons, we choose the SOBI algorithm [10], which incorporates the temporal information, substituting the higher order statistics by time-delayed correlation matrices for source separation. SOBI try to find the unmixing matrix that diagonalizes the cross-correlation matrix of whitened observations at several lags simultaneously. Considering a previous whitening step,

$$\mathbf{z} = \mathbf{W}\mathbf{x} \tag{2}$$

where **z** is the whitened vector and **W** the whitening matrix, the problem is reduced to:

$$\mathbf{z} = \mathbf{U}\mathbf{s} \tag{3}$$

where **U** is a unitary matrix, i.e., the whitened signals are a unitary mixing of the sources, $\mathbf{A} = \mathbf{W}^{+}\mathbf{U}$, where superscript $^{+}$ denotes the pseudoinverse. Note that the whitening process reduces the dimension of the problem. In our case, **x** is a *64x1* vector, so **W** is a *mx64* matrix, where *m* is chosen depending on the estimated number of sources, ideally only two, the AA and VA, but, for practical purposes, 12 in our experiments due to the interest in the extraction of AA and VA subspaces and artifacts as 50 Hz interference and also to be possible the comparison with traditional 12-lead ECGs.

3.2. Identification of the AA

After the application of ICA, 12 sources are estimated. The AA is characterized in the spectrum by a peak around 5 Hz, although other spectral components may appear. After the recovered signals that accomplish this condition are selected, the statistical information is exploited in a second step in order to extract the AA component that maximizes the S/N ratio, i.e., the AA component that minimizes its content of VA and other non AA signals. This is done ordering the AA signals according to their kurtosis. Because the presence of some residual VA will always increase the kurtosis, we identify the final AA as the component with lower kurtosis.

3.3. Reduction of the number of leads and optimal localization

Once the one dimensional AA is obtained, the goal is to obtain which leads out of the 64 are the most contributing to AA. This is easily done in different ways, e.g., analyzing the entries of the row of the unmixing matrix that extract the AA, doing the same with the corresponding column of the estimated mixing matrix (the pseudoinverse of the unmixing one), or correlating the AA with the 64-lead BSPM signals.

This step explains how the AA is distributed over the thorax, a high valuable information for clinical purposes. Compared to traditional 12-lead ECG, BSPM allows a better understanding of the physical process because it gives information of where to emplace the leads in order to maximize the presence of AA in the measurements minimizing the VA.

4. RESULTS

The database corresponds to a 64-lead BSPM recording of two seconds of five patients, including a patient with a pacemaker. The preprocessing is reduced to the baseline and DC removal. No other filtering is carried out, so artifacts due to breathing or 50 Hz interference are included in the data.

First we check the suitability of the model and compare with the results obtained with 12-lead standard ECG [11]. The standard ECG can be obtained from the BSPM data. We define the kurtosis as the parameter to measure the quality of the extraction. It is assumed that a lower kurtosis for the same patient corresponds to a better cancellation of the VA in the AA component. The results confirm that with 64 leads SOBI always extract the AA. However, with the 12-lead data the algorithm fails in one patient. For the rest of patients, with the BSPM data the AA extracted is always better. In Fig. 2 we show the 12 sources extracted, where we can identify the signals of interest, i.e., the AA subspace (sources #4 and #10), the VA subspace and some artifacts, e.g., the 50 Hz interference (source #8) and another harmonic of 55 Hz (source #9). In Fig. 4 we show the spectrum and histograms of the AA sources, being clear that the correct AA is the #4.

In Fig. 5 we represent the entries of the row #4 of the demixing matrix for the leads located on the front of the vest, interpolating with cubic splines. We can see the leads where the content of AA is higher. This is a very useful representation because we can extract how many and which ones are the optimal leads to be selected in order to reduce the number of leads. Finally, in Fig. 6 we represent the signals recovered by SOBI using only leads #13 and #42. As we can see the AA and VA are separated. This is a very important result and a promising method for other ECG-recordings applications. Obviously the extracted AA is not as good as the obtained with more leads. For example, the kurtosis of the AA is -0.5 in this case, while it is -0.8 using two additional leads, #19 and #26, indicating that more VA is present in the estimated AA.

5. CONCLUSIONS

We have presented a BSPM acquisition system in order to optimize the number and localization of leads to extract the AA from AF episodes. We have shown that we can achieve the ideal source separation problem of two mixtures and two sources, the AA and the VA signals for BSPM 64-lead registers.

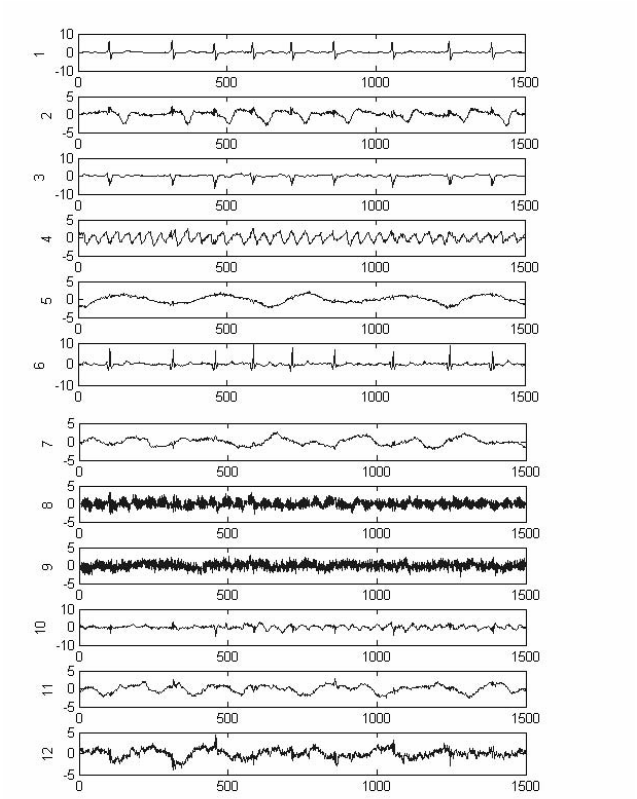

Fig. 3. Recovered sources for a 64-lead BSPM recording. The number of sources is 12.

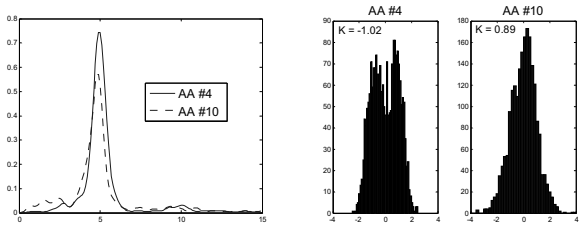

Fig.4.Spectrum of sources #4 and #10 (left) and histogram (right). The kurtosis of #4 is lower than #10, so it is the selected AA.

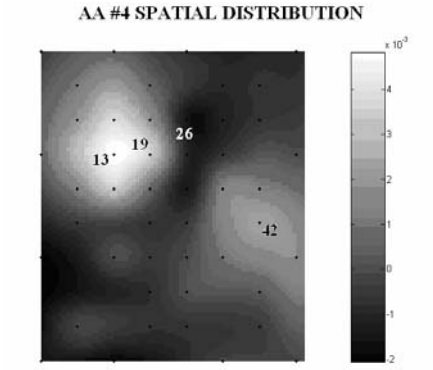

Fig. 5. Entries of row #4 of the unmixing matrix for every lead (front view of the vest). Cubic interpolation is used. Lead #13 is the lead that more contributes to the AA.

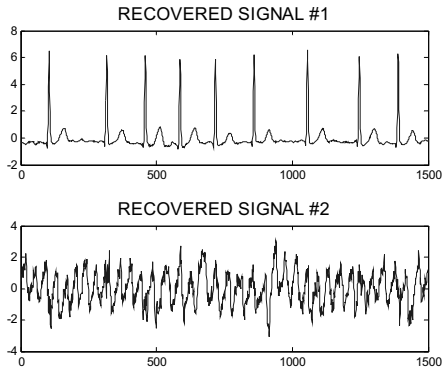

Fig. 6. Recovered sources for a 2-lead register obtained from leads #13 and #42 of the original 64-lead BSPM.

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7. REFERENCES

[1] R. Lux. ‘‘Electrocardiographic Body Surface Potential Mapping’’, *CRC Critical Reviews in Biomedical Engineering*, **8**, pp. 253-279, 1982.

[2] B. Taccardi, B.B. Punske, R.L. Lux, R.S. Macleod, ‘‘Useful Lessons from Body Surface Mapping’’, *Journal of Cardiovascular Electrophysiology*., **9-7**, pp. 773-786, 1988.

[3] McClelland, A. J., Owens, C. G., Menown, I. B., Lown, M., and Adgey, A. A. “Comparison of the 80-lead body surface map to physician and to 12-lead electrocardiogram in detection of acute myocardial infarction’’. *Am.J.Cardiol.* 92[3], 252-257. 2003.

[4] Montague, T. J. and Witkowski, F. X. “The clinical utility of body surface potential mapping in coronary artery disease.”, *Am.J.Cardiol*. 64[5], 378-383. 1-8-1989.

[5] Maynard, S. J., Menown, I. B., Manoharan, G., Allen, J., McC, Anderson J., and Adgey, A. “A. Body surface mapping improves early diagnosis of acute myocardial infarction in patients with chest pain and left bundle branch block”. Heart 89[9], pp. 998-1002. 2003.

[6] http://www.biosemi.com/

[7] S. Shkurovich, A. V. Sahakian, and S. Swiryn, "Detection of atrial activity from high-voltage leads of implantable ventricular defibrillators using a cancellation technique", *IEEE Transactions on Biomedical Engineering*, vol. 45, no. 2, pp. 229-234, 1998.

[8] P. Comon, “Independent Component Analysis, a new concept?”, *Signal Processing, Vol. 36*, pp 287-314, 1994.

[9] J. J. Rieta, V. Zarzoso, J. Millet, R. Garcia, and R. Ruiz, “Atrial Activity Extraction Based on Blind Source Separation as an Alternative to QRST Cancellation for Atrial Fibrillation Analysis”, *IEEE Computers in Cardiology*, vol. 27 pp. 69-72, Sep. 2000.

[10] A. Belouchrani, K. Abed-Meraim, J.F. Cardoso, “A Blind Source Separation technique using second-order statistics”, *IEEE transactions on Signal Processing,* Vol. 45, No. 2, pp. 434-444.

[11] F. Castells, J. Igual, J. Millet, J.J. Rieta, “Atrial activity extraction from atrial fibrillation episodes based on maximum likelihood separation”, *Signal Processing*, Vol. 85, Elsevier, pp. 523-535, 2005.