# INDEPENDENT COMPONENT ANALYSIS FOR MOTION ARTEFACT SUPPRESSION

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## ABSTRACT

Independent component analysis seems to be promising tool for analysis of optical signals recorded from the heart surface. Optical signals reflect electrical phenomenon in the heart, however their evaluation complicates motion artifact. This artifact can be successfully removed by usage of specific ICA algorithms. Twenty-six ICA algorithms were used in this work. Results of ICA algorithms were compared with result obtained by another method usually used for motion artifact removing. Seven ICA algorithms were found as usable for motion artifact removing.

## 1. INTRODUCTION

For diagnosis of the heart can be used action potential (AP). AP in cardiological experiments at animal models can be measured by optical method. However, AP is often devaluated by motion artefact, which is blended with AP.

Independent component analysis (ICA) is a statistical and computational technique for revealing hidden factors that underlie sets of random variables, measurements, or signals [1]. ICA seeks to transform the original data set into a number of independent variables. The motivation for this transformation is to uncover more meaningful variables [2].

Optical signal recorded from the heart surface represent mixture of action potential and motion artefact. Attributed of this mixed signals suggest, that ICA can be used for motion artifact removing.

## 2. METHOD

### 2.1. OPTICAL RECORD OF ACTION POTENTIAL AND ORIGIN OF MOTION ARTEFACT

Action potential (AP) is recorded by optical method based on fluorescence measurement. Electrical activity of the cells is transformed into light by voltage-sensitive dye and measured by three photodetectors [3]. However, the change of detected light intensity, caused by heart motion, affects the monitored action potential. Distance between the heart surface and photodetectors is changed during contraction of beating heart and affects intensity of the detected light. This unwanted phenomenon is called motion artefact (MA). The AP is affected by MA in the heart and its mechanical contraction leads to mixture signals.

Intensities of light detected in three different wavelength bands (red, green and blue) during one heart cycle are shown in the Figure 1. The action potential and motion artifact are mixed in the red and green part and blue part contains only motion artifact. This proposition is deduced from knowledge of electrical activity of heart and spectral properties of applied voltage-sensitive dye.

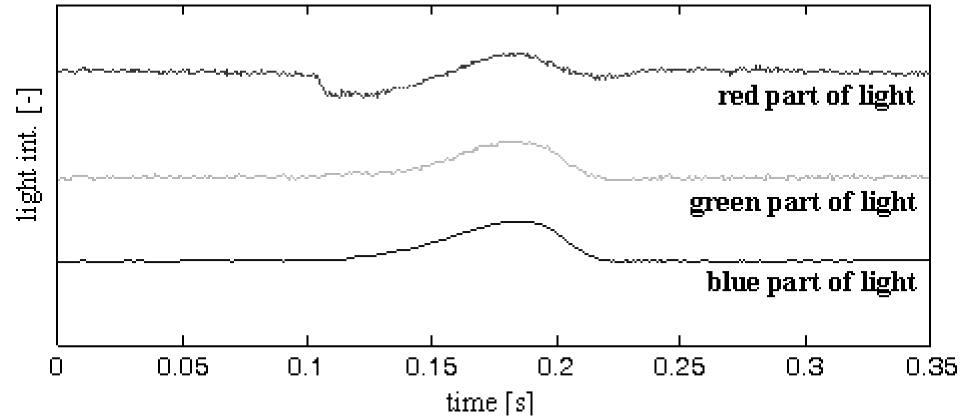


**Figure 1**: Parts of light collected from the heart surface in one heart period.

Recording setup for fluorescent measurement in our experiments was not calibrated due to lack of a proper calibration method (Fig 1.). AP derived from this measurement is presented as a relative signal. However the range of AP is well-known: <-90mV; 0mV>, therefore AP can me normalized (Fig. 2).

### 2.2. Ratiometric method

Ratiometric method is commonly used for deriving of AP from optical records. In this article ratiometric method was used as standard and proposed ICA was compared with this method. Action potential (Fig. 2) was obtained from optical signals (Fig. 1) by ratiometric method. There is a small resting MA in AP course, caused by used equipment (spectral bands are not separated completely; there is an overlap between bands caused by used photodetectors).

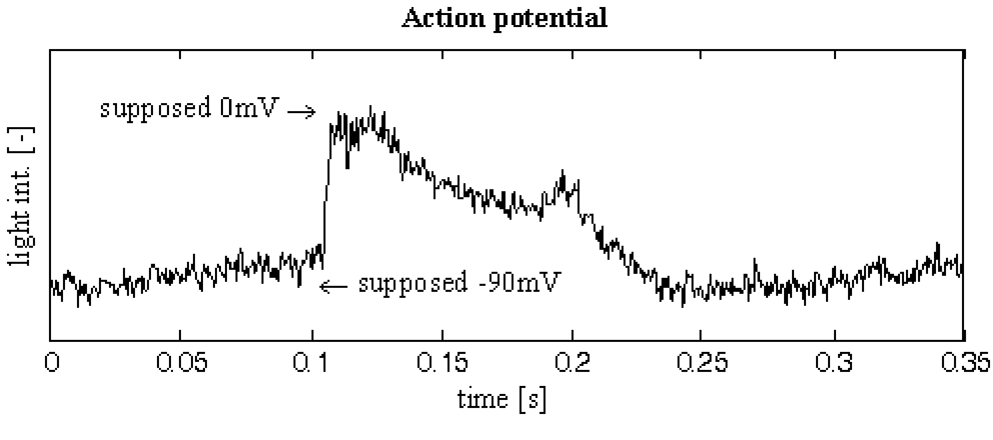


**Figure 2:** Action potential obtained by ratiometric method.

Action potentials obtained by ICA were compared with this result (AP at Fig. 2) obtained by ratiometric method. The same input signals were used for both methods.

### 2.3. INDEPENDENT COMPONENT ANALYSIS

ICA belongs to blind source separation methods. "Blind source" means that ICA allows separating independent variables from some linear mixtures without knowledge about character of separated signals. ICA uses high order statistic. Variables with a Gaussian distribution have zero statistical moments above second order, but most signals do not have a Gaussian distribution and do have higher order moments. These higher order statistical properties are put to good use in ICA [2].

The basis of most ICA approaches is a generative model; that is, a model that describes how the mixed signals are produced. The model assumes that the mixed signals are the product of instantaneous linear combination of the independent sources. Such a model can be stated mathematically as:

$$x_i(t) = a_{i1}s_1(t) + a_{i2}s_2(t) + ...a_{iN}s_N(t) \quad (1)$$

where *x(t)* are the signals obtained from the sources, *s(t)* [2]. Optical signals in this study comply with this model.

### 2.4. NUMBER OF INDEPENDENT COMPONENTS

Scree plot of eigenvalues reveals number of independent components. The shape break at number=2 (not shown) suggests two independent variables in the data set.

### 2.5. RESTRICTION OF ICA

Usage of ICA has two conditions: source signals (AP and MA in this article) have to be (1.) nongaussian and (2.) statistically independent. Nongaussian character of AP and MA are shown in Figure 4. Estimation was based on a normal kernel function [5]. Chi-square goodness-of-fit test ($\alpha = 0.05$) confirm, that both of signals are really nongaussian. The 1$^{st}$ condition is therefore entirely fulfilled.

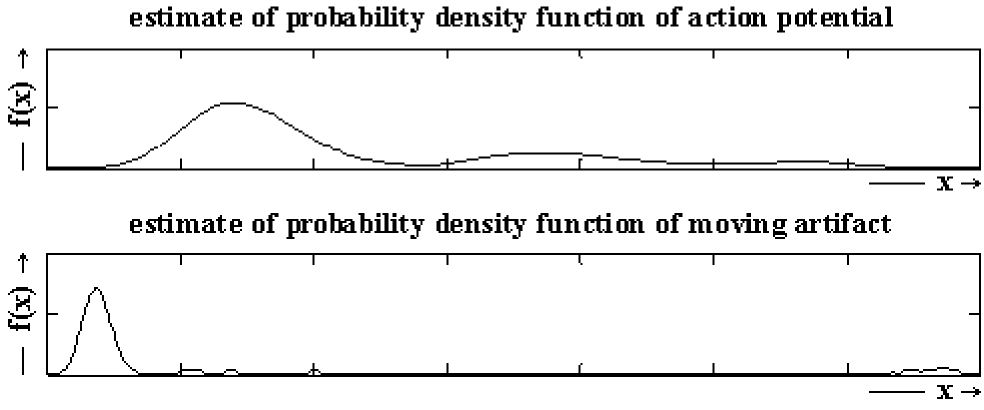


**Figure 4:** Action potential and motion artefact are nongaussian. Signal obsahuje hodnoty x jejichž četnost je dána f(X)

The 2$^{nd}$ ICA condition is statistical independency of source signals. Exact computation of independency of real signals requires a sufficiently large amount of joint data. However, independency can be appraised by comparison of the joint histogram and product of separate histograms. In case of independency the joint histogram is equal to product of separate histograms.

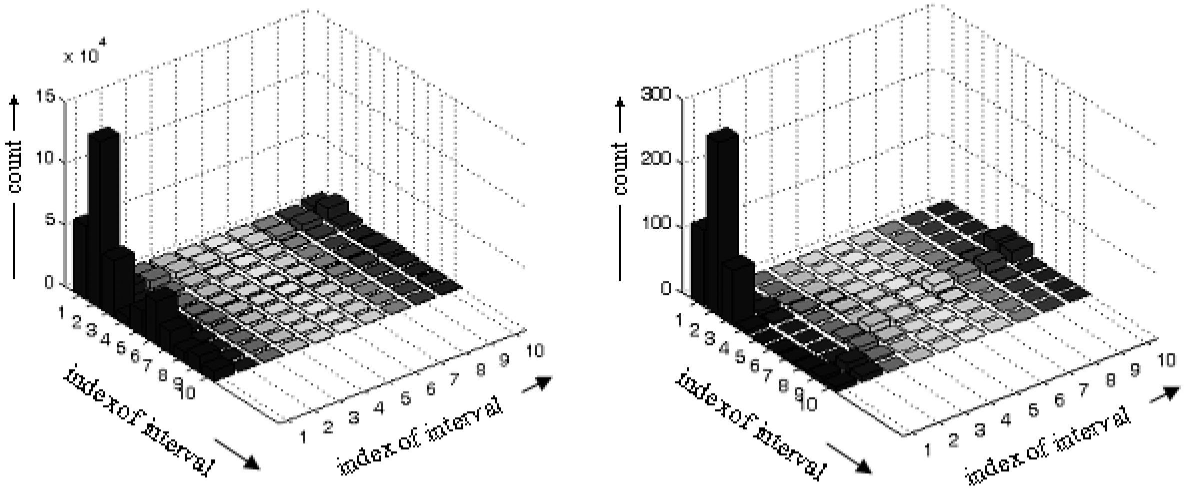


**Figure 5:** Left: product of separate (MA, AP) histograms; right: joint histogram. Histograms were not normalized.

Comparison of histograms and the joint histogram (Fig. 5) reveals that MA and AP are not completely statistically independent. Nevertheless dependency of MA and AP is small, and some ICA algorithms give satisfactory results.

# RESULTS

## 2.6. Efficiency of ICA algorithms

Efficiency of used ICA algorithms was evaluated by comparison of AP obtained by ICA with AP obtained by ratiometric method (Example at Figure 5). Correlation coefficient was computed between both these APs. Source signal for both methods was the same – it was one heart beat period, averaged from of 70 heart periods. Correlation coefficient more close to 1 determines better ICA result. Coefficient higher than 0,99 shows ICA algorithms, which can be successfully used for revealing of AP from mixed signals.

The 26 ICA algorithms were tested: AMUSE, COMBI, EFICA, ERICA, EVD2, EWASOBI, FAJDC4, FJADE, FOBI-E, FPICAJ, JADETD, JADEop, MULTICOMBI, NG-FICA, QJADE, SAD, SANG, SIMBEC, SOBI-BPF, SOBI-RO, SOBI, SONS, SYM-WHITE, ThinICA, UNICA, WASOBI. Description of this algorithm can be found at [4].

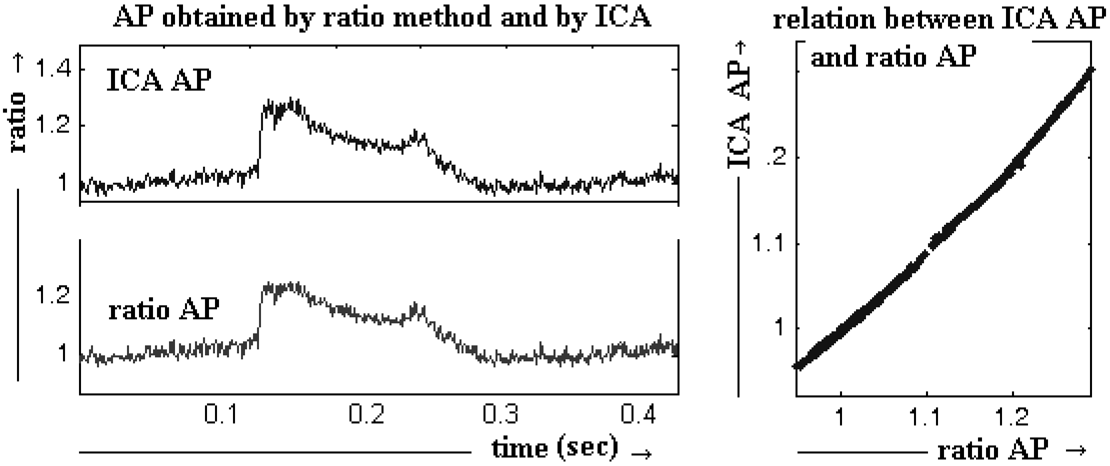


**Figure 5:** Left: APs obtained by ratio method and ICA. Right: Ratio AP versus ICA AP.

Seven ICA algorithms can be successfully used for AP revealing. They are ordered (according to value of correlation coefficient) in Table 1:

| ICA ALGORITHM | CORR. COEF. |
|---|---|
| UNICA (Unbiased quasi Newton algorithm for ICA) | 0,9985 |
| FOBI-E (Fourth Order Blind Identification with Transformation matrix E) | 0,9953 |
| EVD2 (BSS SOS algorithm based on symmetric EVD) | 0,9951 |
| AMUSE (Algorithm for Multiple Unknown Source Extraction based on EVD) | 0,9947 |
| JADETD (HOS Joint Approximate Diagonalization of Eigen matrices with Time Delays) | 0,9936 |
| ERICA (Equivariant Robust ICA - based on Cumulants) | 0,9934 |
| SONS (Second Order Nonstationary Source Separation) | 0,9901 |

**Table 1**: ICA algorithms suitable for analysis of action potentials recorded by optical method from living heart surface.

## 3. CONCLUSION

Seven ICA algorithms (UNICA, FOBI-E, EVD2, AMUSE, JADETD, ERICA and SONS) can be used for motion artifact suppression. These algorithms can reveal AP with very good accuracy; however none of them is able to simultaneously reveal MA with sufficient precise. Nevertheless AP is object of interest, not MA. It can be therefore concluded that ICA is usable tool for analysis of optical signals, which are degraded by motion artefact.

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