De-noising of experimental signals from pyroelectric sensors by a source separation method

R. Huez, D. Nuzillard, A. Billat
Laboratoire d'Automatique et de Microélectronique ,
Moulin de la Housse,
BP 1039 - 51687 REIMS Cedex 2, France
e-mail: `regis.huez, danielle.nuzillard, alain.billat, @univ-reims.fr`

ABSTRACT

The aim of this work is to de-noise experimental signals from pyroelectric sensors. Its originality lies in the use of a double pyroelectric sensor especially designed to receive an instantaneous linear mixing of signals. The centre of the sensor receive mainly the signal, its periphery picks up mainly noise. The signal is processed with a separation source method enabling in this way to exploit the possibilities of this new device. The setting up of such a device has never been done previously neither in the view of experimentation nor in the view of information processing.

1 Introduction

In the aim of promoting agricultural resources, we are studying the mechanical behaviour of biodegradable material such as starch, and in particular, we strive to determine the humidity profile inside the material. The sample is lit by a laser diode beam, the wavelength of which is equal to 1.935 μm, which matches a water absorption band. The modulation of the laser diode enables us to stimulate the water contained in the sample at different depths (similar to skin effect). The presence of humidity in the sample leads to a warming up distributed according to depth. Measuring the temperature variations on the surface of the sample for different frequencies of the exciting radiation will enable to deduce the humidity profile by inverse methods. To avoid the destruction of the biopolymer material during the analysis, it is necessary to use a low power excitation of the diode which induces non-linearities in the operating mode. The flow of heat coming from the sample is gathered up by a pyroelectric sensor placed underneath the sample [1]. Identification of the system is done by a digital synchronous filter. After some first tests, we obtained an important dispersion in the measurements. We have reduced this one by using two double sensors, each associated with a source separation method.

2 Experimental setup

The dispersion of measurements has two causes :

- An intrinsic noise coming from the electronic and optical components located between the signal sent by the processing system and the one received on the sample (original signal plus supply noise and laser diode non linearities...).
- An unknown noise coming from the experimental environment is picked up on the sensor (speech, vibrations...).

The problem of the intrinsic noise is solved by using an second pyroelectric sensor. It received a part of the optical beam. Its response is considered as the reference signal. The problem of the external noise is more subtle to solve. Pyroelectric sensors are very sensitive. The reference sensor and the measurement sensor don't perceive the environmental noises in the same way. The classical methods of de-noising are inefficient because they need to have a good noise reference. In this experiment, we have chosen to use two double sensors in association with a blind separation source method. The first one is the measurement sensor and the second one the reference sensor. A double sensor is made up from a single pyroelectric sensor. A disc of pyroelectric material (10 mm diameter and 0.2 mm thickness) is covered with metallic electrodes on each side. The lower electrode is divided in two distinct electrodes by demetalization of a central ring. We obtain a central sensor made up of pyroelectric material placed in the central part of the lower and upper electrode. In the same way we obtain a peripheral sensor from the peripheral part of the lower electrode. The laser beam has a Gaussian spatial distribution of energy. Its diameter is 5 mm. The sensor central part strongly perceives the signal coming from the beam and the external noise. The surface of the peripheral ring is three times bigger. So it is strongly influenced by the external noise and less by the signal coming from the beam. An interfacing system made in the laboratory enables us to obtain numerical signals from the sensors. The reference double sensor used in the experimental device associated with a source separation method is then used to separate the incident source signal coming from the laser beam with all its imperfections from the environmental noises. Only these results are reported in part 4 of this paper. The modulation frequency of the diode can be arbitrary chosen in a range between 0.1 and 100 Hz. At these frequencies, the lateral propagation of the thermal waves is very weak. The signals received on each double sensor can then be considered as an instantaneous mixing.

3 Signal Processing

The new use of this double sensor with the source separation method enables us to isolate the beam from the surrounding noise in order to obtain a better image of the energy absorbed and scattered by the sample. By de-noising [2], we find the true representation of the excitation. In this way, we ensure the best conditions in the treatment of experimental measurements and a better respect for the laws of physics. The sensor receives a signal $s(t)$ which is a mixing of the beam $e(t)$ and of external noises $b(t)$. All these noises from different origins, such as thermal, electric, acoustic or mechanic are not controllable. They have a Gaussian tendency and they are coloured. By its design, the supply of the diode excitation can generate a variable frequency but also, a fixed frequency of 100 Hz (that can't be eliminated) which is a parasite in this application. The laser diode working itself introduces harmonics of the exciting frequency. The available output signal of the sensor is of this type : $s_i(t) = \alpha_i.s(t) + \beta_i.b(t)$ where α_i and β_i are proportionality factors. Considering the noise $b(t)$ as being an independent source, implies that the algorithms operate with no additional noise. The mixing matrix elements can be extracted by block algorithms working on instantaneous mixtures such as :

- ICA (Independent Component Analysis) [3],
- JADE (Joint Approximate Diagonalization of Eigen-matrices) [4], [5],
- SOBI (Second Order Blind Identification) [6].

4 Results

Results obtained with the JADE, SOBI, and ICA algorithms are equivalent. The two experimental data sets presented here were processed with the SOBI algorithm. The first one is shown in fig.1 and fig.2 ; the second one is in fig.3 and fig.4, each with respect to time domain, and to frequency domain. The modulation frequency of the current in the diode is 10 Hz. The sensor responses are in fig.1a and fig.1b. The estimated sources are the retrieved excitation (fig.1c), whose noise has been nearly erased and the noise itself, drawn as well in fig.1d. The dashed circles clearly display the separation effect of the two most visible perturbations. These same signals are presented in the frequency domain from fig.2a to fig.2d. Due to the high energy of the 10 Hz peak with regard to the noise intensity, we have to magnify the representation of the signal sensor 1 (fig.2a) as well as the estimated signal source 1 (fig.2c); this enlargement is made with the same ratio. Figure 2a shows the perturbations located at the 110 Hz to 160 Hz range. After the source separation processing (fig.2c), they are totally erased. On the contrary, the 100 Hz peak and those corresponding to the harmonics which are generated by the diode remain there. It is quite logical because they are part of the exciting signal. The erased contribution corresponding to the noise is retrieved in the second estimated source (fig.2d).

The second experimental data set (fig.3 and fig.4) has been chosen because the perturbations and the signal are in the same frequency range. The estimated source 1 was clean up. In spite of the high energy of the 10 Hz peak, the second sensor (fig.3b, fig.4b) is informative enough to retrieve the signal (fig.3c, fig.4c), and the noise (fig.3d, fig.4d).

5 Further works

The source separation method seems to be promising for this kind of application. Studies will be done with more sensors made from a single pyroelectric material whose electrodes will be judiciously engraved. They should improve the signal noise ratio. More, they should allow to distinguish a dominant noise from others especially mechanical or acoustic noises. Then the source signal image coming from the separation will enable us to adjust the reference signal which will be used in further processings.

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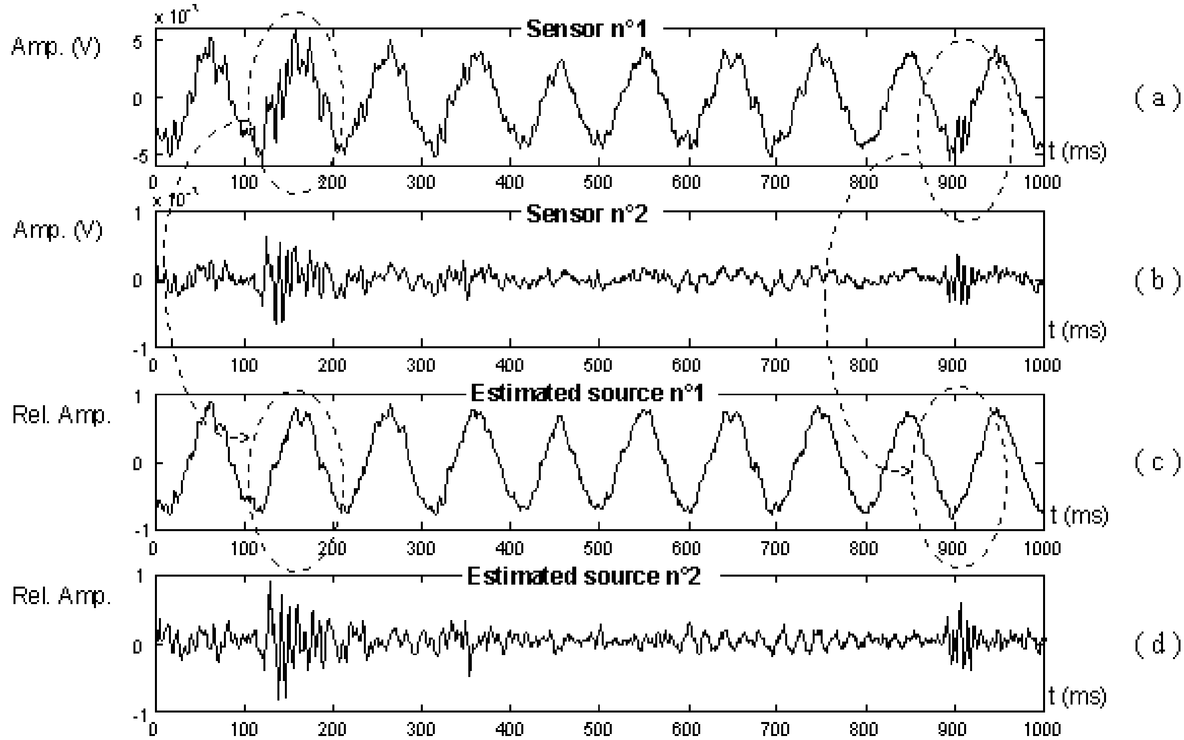

Figure 1: First experimental data set - time domain

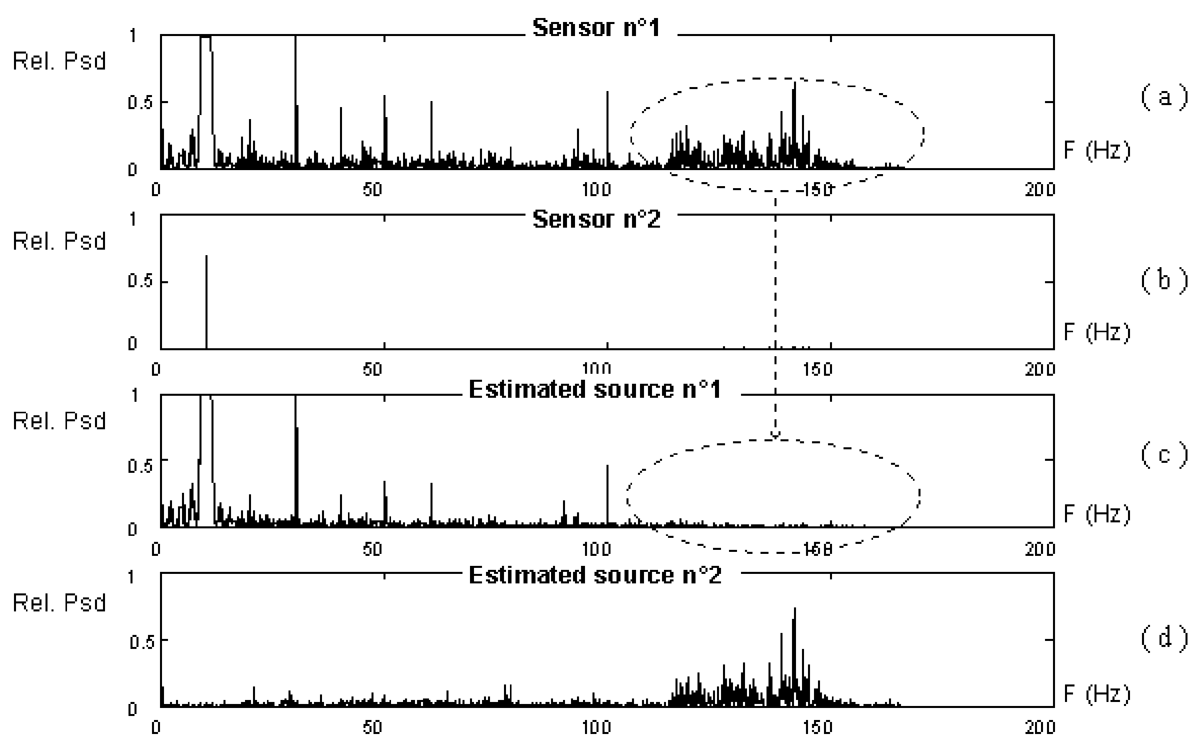

Figure 2: First experimental data set - frequency domain

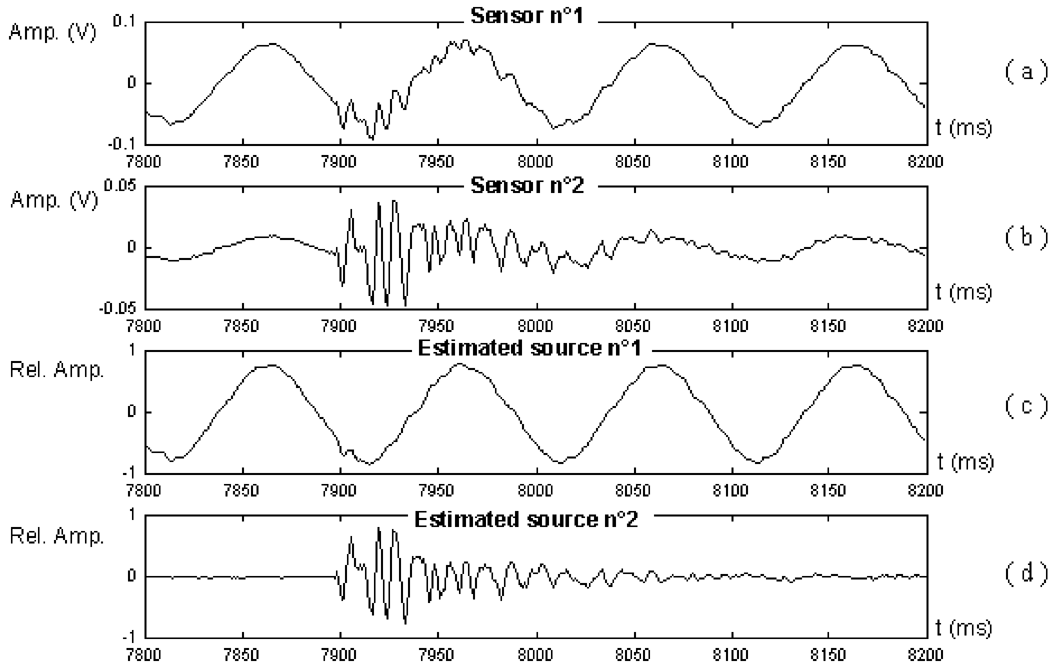

Figure 3: Second experimental data set - time domain

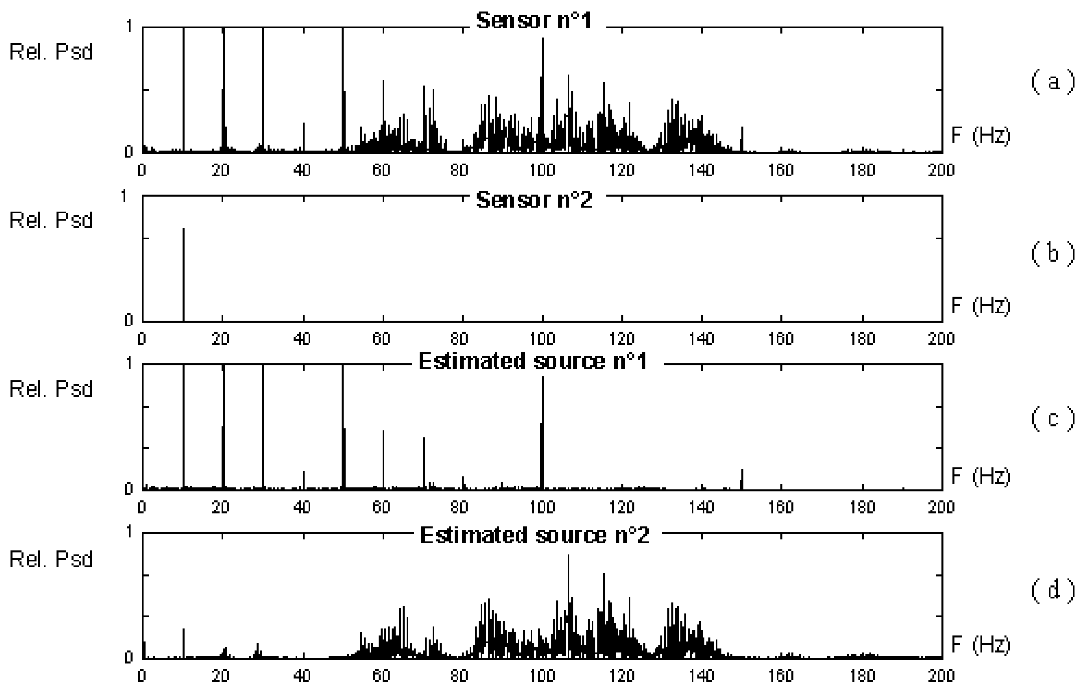

Figure 4: Second experimental data set - frequency domain