Blind separation of sources applied to convolutive mixtures in shallow water

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Abstract :

In underwater acoustics, the signal received by sensors is a mixture of different elementary sources, filtered by the environment. In blind separation of sources, we can isolate each source from different mixtures of sources without any a priori information, except for assuming statistical independence of the different sources. Two French researchers, J. Herault and C. Jutten had earlier proposed a neuromimetic solution to the problem.
In our work, we use this solution to separate convolutive mixtures of simulated complex underwater signals in shallow water environment. To allowed the multipath identification a whitening step have to be introduced. We propose a local whitening procedure that does not impact the separated signal output and preserve the signal characteristics
This promising technique can be improved using non causal whitening filters more adapted to the target environment.

Keywords : shallow water propagation, source separation, multipath identification, whitening.

1. Introduction

The Blind Separation of Sources problem arises from different fields such as astronomy, astrophysics, underwater acoustics, medical applications. According to the domain, one can focus on an object (star, ship, electrocardiogram wave, etc.) that produces some signals (optical, electromagnetic, acoustics signals, etc..)

In underwater acoustic, the signal received by sensors is a mixture of different elementary sources, filtered by the environment. For example, these different sources could be the signatures of vessels, the noise made by the environment, self-noise, etc..

The optimal use of the sensors will be to separate all these sources. This issue is called blind separation of sources because we do not have any a priori knowledge about these sources : the only hypothesis made is that they are statistically independent.

The sources path trough a transmission field are received on a set of sensors.

The transmission field is supposed to be isotropic deterministic, to present a stationary property and furthermore to be linear. So the received signals can be considered as linear mixtures of the initial sources.

Using only the knowledge of the received signals, one can try to characterise the initial sources.

The sources are supposed to be in a shallow water environment The signals are simulated and the mixtures received by the sensors are convolutive.

The separated signals will be used for several purposes such as detection, noise reduction, classification etc.. For this applications it is important to preserve as much as possible the initial sources characteristics. The proposed algorithm is design in this way.

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2. Propagation characteristics

In the shallow water environment, the signal received by the hydrophone is the result of the direct sound added with the echoes of the source.

Depending on the position of the source, and the receiver, the propagation effect can be modelled as a linear time-invariant filter H_{ij}. The impulse response $h_{ij}(t)$ of the filter can be estimated with GAMARAY, a ray-based model developed by E. K. Westwood [5].

Most of the taps of the impulse response are equal to zero ; the non null taps are representative of the direct sound and the echoes. Typical impulse responses of the filters, for two different positions source-receiver, are shown on the figure 1 :

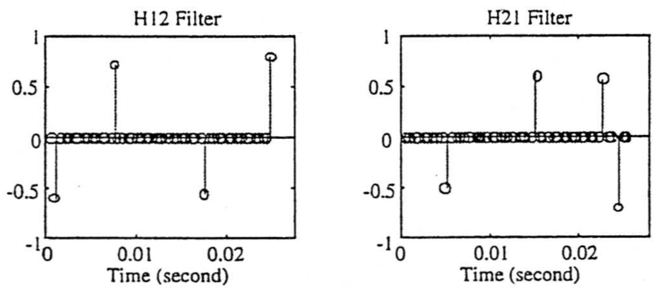

Figure 1 : Propagation effect in shallow water environment. Impulse response of two different filters H_{12} and H_{21} estimated by GAMARAY.

The received signal $r_j(t)$ on the hydrophone j is the contribution of each source signal , filtered by the environment :

$$r_j(t) = \Sigma\, h_{ij}(t) * s_i(t) \quad i = \{1, ..., M\} \quad (1)$$

For two hydrophones R_1 and R_2 and two sources N_1 and N_2, the received signal can be modelled as convolutive mixtures as shown on the figure 2.

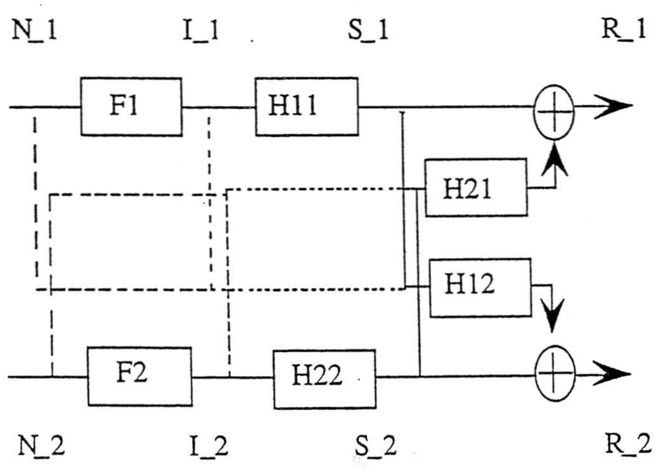

Figure 2 : Received signals generation

Starting from white noise processes N_1 and N_2, the initial sources I_1 and I_2 are obtained by linear filtering respectively F1 and F2.

Then they propagate trough the media. During the propagation to each sensor R_1 and R_2 a transformation is performed respectively by the filters H_{11} and H_{22} and the coloured sources S_1 and S_2 are obtained.

It is clear that the filters H_{11} and H_{22} could not be estimated using independence properties of the sources because all the signals of a defined line (N_i, I_i, S_i) are independent to the signals taken on an other line (N_i, I_i, S_i). Further hypothesis have to be stated to define the point to be reached.

The signals received on R_1 and R_2 are convolutive mixtures of S_1 and S_2. The filters H_{12} and H_{21} are a model of the propagation in shallow water.

The filters H_{12} and H_{21} could be estimated by restoring the independence properties of the output of a system build as a mirror image of the propagation.

3. Source separation principle

The algorithm proposed in [3] can be seen as an invert propagation procedure.

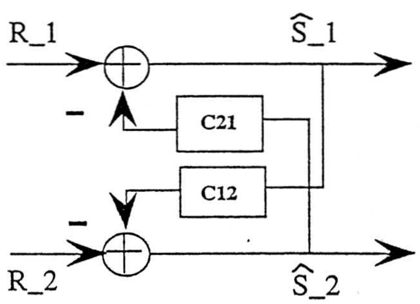

Figure 3 : Estimation of the sources S1 and S2 by invert propagation procedure.

The problem is now an identification one using a neural net.

The estimation of the separating filters C_{12} and C_{21} is based on the minimisation of the cross information of the network output. The cross information can be quantify using various statistics. Quadratic, higher order or non linear solutions exist and the choice depends on the application type.

From our experience, the results are similar in terms of performance and tracking capability. The different memory parameters involved in the various algorithms have to be optimised depending on the local or statistical properties of the sources.

An important point to underline is that the separating filters C_{12} and C_{21} would be equal to the mixture filters H_{12} and H_{21} if the sources S_1 and S_2 are equivalent to a white noise [4].

As an example let us consider a mixture of two white noises. The first one is a realisation of a uniform distribution and the second is obtained by taking the Arctang of a gaussian process.

The filters H_{11} and H_{22} are equal to 1 and the impulse responses of filters H_{12} and H_{21} present a sparse corresponding to a shallow water propagation distribution (Figure 1).

The independence criteria is the fourth order cross moment of the estimated signal. 10 000 points are used for this simulations.

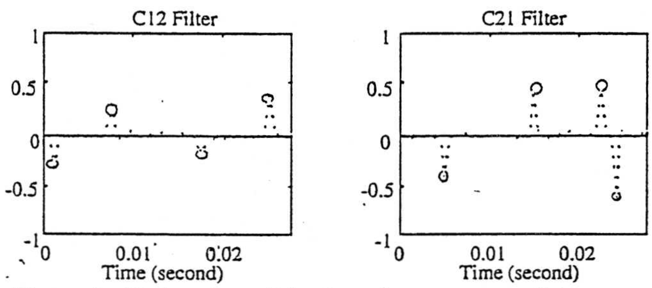

Figure 4 : Estimation of the impulse response of the two separating filters C_{12} and C_{21}

The rough results are presented on figure 4, using a dash line. One can see that a post processing is possible by identifying the main propagation path : the impulse responses of the filters C_{12} and C_{21} are close to the typical impulse responses used for this simulation (cf. figure 1).

Because of the particular shape of the filters H_{12} and H_{21}, only maxima values have to be taken into account to identify the impulse responses of the separating filters C_{12} and C_{21}.

This reconditioning will remove the variance estimation of the null taps of the filters. In some cases, those variations can represent the major part of the separating filters and lead to poor separation results.

4. Local whitening Algorithm

The underwater sources are not white processes so a whitening step have to be done to come back to the previous case and identify the main path components.

If a pre-whitening is performed the separated sources have to be coloured to be used for identification purposes. To avoid doing this back and forth procedure, we propose to do the whitening step just where it is needed. This is to say for the separation filters C_{12} and C_{21} updates.

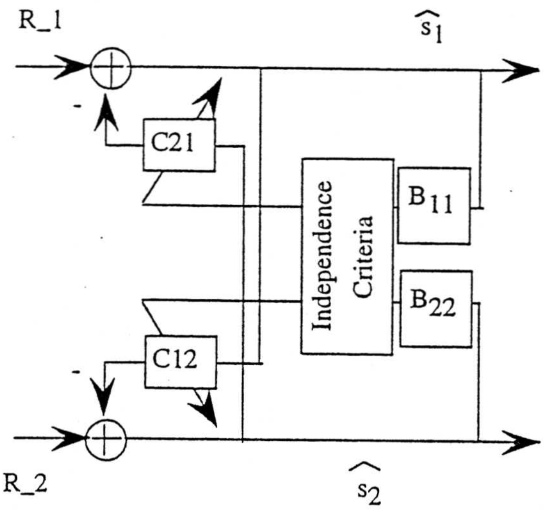

Figure 5 : Estimation of the sources S1 and S2 by invert propagation procedure and local whitening.

The output equation is still the same :

$$\begin{aligned} \hat{s}_1 &= R\_1 - C_{21}\,\hat{s}_2 \\ \hat{s}_2 &= R\_2 - C_{12}\,\hat{s}_1 \end{aligned} \qquad (2)$$

But the updating independence criteria are not estimated directly on the output signal but on the whitened versions of them.

The algorithm can be summarised with the following lines of pseudocode.

```
For all samples
  Begin
  Estimated the whitening filter taps B1
      and B2 using the output signal.
  Estimate the independence criteria
      (Indep) using the whitened output signal.
  Update all the coefficients using :
      Cij (t+1) = Cij (t) + µ  Indep
  Estimated the output signals
  End
```

The following example presents the results of underwater signal mixed using the same filters than previous example.

The first source is a submarine signal and the second a ship noise.

The sampling frequency is 2000 Hz, and the signal duration is equal to 10 seconds.

Using the local whitening algorithm, the estimated impulse responses of the filters C_{12} and C_{21} are presented on figure 6.

The whitening filters B_{11} and B_{22} are 50 taps FIR filters.

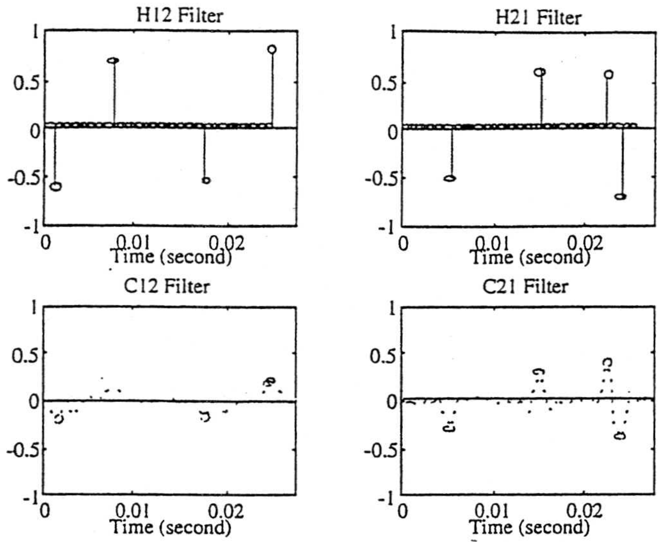

Figure 6: Estimation of the two separating filters C_{12} and C_{21} using local whitening algorithm.

The results are promising - the estimated filters C_{12} and C_{21} are close to H_{12} and H_{21} - but can be improved. So the identification of the main propagation path could be done for coloured sources.

The source separation filters are only related to the propagation and not to the colour of the sources.

By doing a local whitening, the estimation of the filters are only related to the independence properties of the sources and not to their respective colours.

5. Conclusion

We present here the first results of sources separation technique applied to underwater acoustic in shallow water.

We propose a local whitening version of the neuromimetic approach proposed in [4]. The purpose is to avoid unnecessary prewhitening / unwhitening operations. Moreover by doing a local whitening procedure for the separating filters estimation, the impulse response of the propagation channel can be identified.

This offer the opportunity to constraint the estimation using the knowledge of the media, and improve the results.

Some improvement of the whitening procedure have to be done and come closer to the results obtained using white noise sources.

Two ways for improvement can be investigate : the use of IIR filter and the estimation of non minimum phase filters. This non minimum phase filters will be mandatory as long as the filters will no longer be equal to 1. Various Blind deconvolution algorithm using non linear criteria can then be used [1], [2].

The first results confirm the possible use of sources separation technique for underwater applications.

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