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A new cerebral micro-emboli detector

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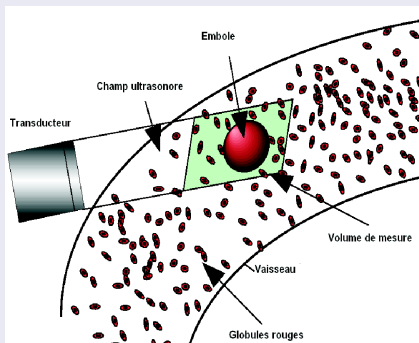
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Introduction

The detection of cerebral micro-emboli:

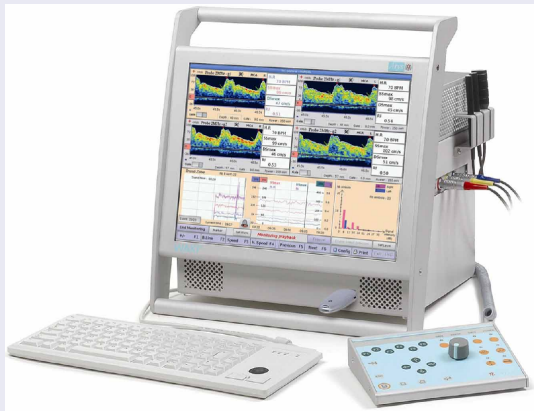
Cerebral Vascular Accidents (CVA):

- third cause of mortality behind cancers;
- first cause of handicap;
- bleedings (20%) et strokes (80% for which 30% are micro-embolisms);
- + 100 000 persons are concerned per year.



Cerebral micro-emboli: micro-particles of different nature: fat, thrombus, clot, air bubble.

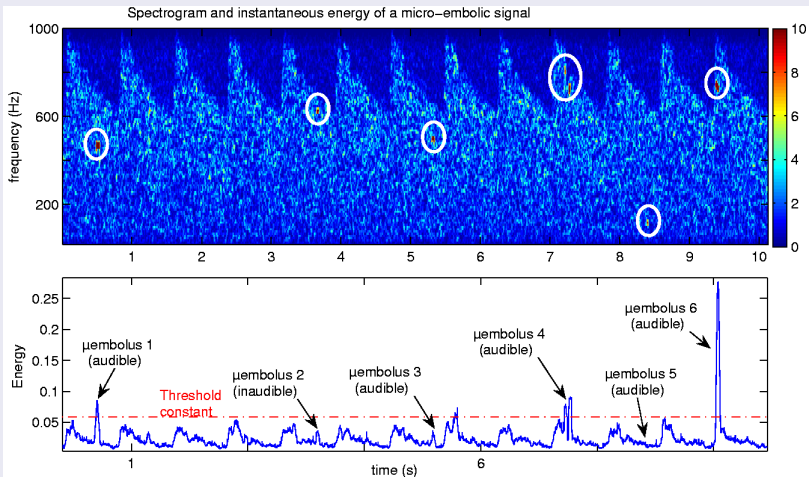
Detection of cerebral micro-emboli:



- Standard techniques implemented in TCD systems seem to be sufficient to detect most of micro-embolic events.
- Nevertheless during clinical examinations, it sometimes happens that a medical expert observes micro-embolic signatures not detected by the system.

This concern has led our team to analyze the signals in another way.

Detection of cerebral micro-emboli:



Existing methods:

- Auditive detection (Doppler): hold Gold standard^a;
- Auditive detection + spectrogram visualization (Doppler): Gold standard ^b;
- Energy detection (Doppler & RF)^c;
- Energy detection in sub-bands (Doppler)^d;
- Energy detection by Matching pursuit (Doppler)^e;
- Neuronal Network Detector (RF)^f;

^aSpencer et al.

^bSpencer et al.

^cSpencer et al.

^dMarkus et al.

^eDeviust et al.

^fN. Benoudjit et al., Ultrasonics 2010

Our contribution:

- Detection of Model's breaking (Doppler)^{a,b};
- Detection of AR parameters (Doppler)^c;
- Synchronous energy detection (Doppler)^d;
- Neuro-fuzzy Detection (Doppler)^e;
- Sub-bands synchronous energy detection (Doppler)^f;
- **Detection of GARCH parameters (Doppler).**

^aGirault et al., IEEE Trans. BME 2000

^bBiard et al., ITBM-RBM 2004

^cGirault et al., IEEE Trans. BME 2000

^dGirault et al., GRETSI 2005

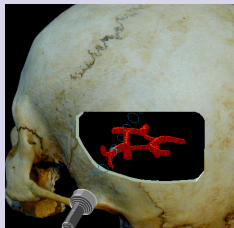
^eKouamé et al., IEEE Trans. ITBM 2006

^fGirault, Hermes-Lavoisier 2010

Materials

Materials:

- 1 Experimental setup;
 - TCD system Waki;
 - Pulse Doppler: 1 gate and 1 transducer;
 - 2 MHz, PRF=6.4 kHz, 150 mW/cm²;
- 2 Synthetic micro-embolic Doppler signals;
 - Modulated (AM, FM) stochastic signal;
 - Micro-embolic energy lower than the maximum systolic energy;
- 3 *In vivo* Doppler recordings;
 - Middle cerebral artery (5cm);
 - Patient with carotidian stenosis.



Methods

Methods:

Here, 3 methods will be presented:

- 1 Standard energy detector;
- 2 AR parameters detector;
- 3 GARCH parameters detectors.

For each method, a decision information (DI) has been evaluated and tested with a short-time analysis as follows:

$$DI(k) \begin{matrix} H_1 \\ \geq \\ H_0 \end{matrix} \lambda \quad (1)$$

k is the number of the analysis window, λ is a threshold, H_1 is the hypothesis for which an embolus is present, H_0 is the hypothesis for which an embolus is not present.

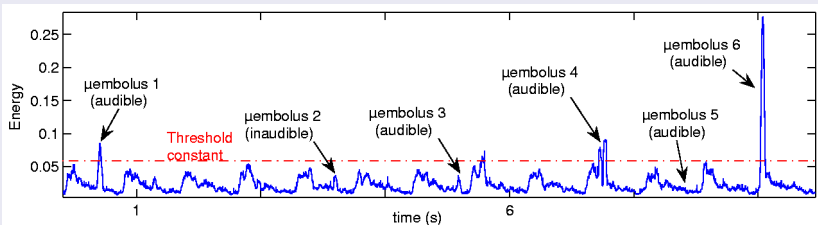
Standard energy detector:

1. Frequential energy estimator:

$$P(t, f) = \left| \int_{-\infty}^{+\infty} x(\tau) g^*(t - \tau) e^{-j2\pi f \tau} d\tau \right|^2, \quad (2)$$

2. Decision Information (DI):

$$DI_1(t) = \max (P(t, f))|_f \quad (3)$$



Auto Regressive (AR) parameters detector:

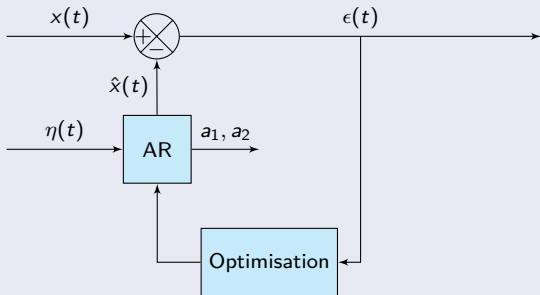
The AR model is defined as follows:

$$\hat{x}(n) = - \sum_{i=1}^p a_i x(n-i) \quad (4)$$

where a_i are AR parameters, p is order of the model (number of coefficients). As an AR(2) is sufficient to detect micro-emboli, the DI proposed evaluated at each k position of the analyzing window, were:

$$DI_2(k) = \max (a_1(k))|_k,$$

$$DI_3(k) = \max (a_2(k))|_k.$$



GARCH parameters detector:

Doppler signal is assumed to be modeled by: $x(n) = \epsilon(n)\sqrt{\sigma^2(n)}$, where $\epsilon \approx N(0,1)$. The Generalized Auto-Regressive Conditional Heteroskedastic- GARCH(p,q) model of the conditional variance σ^2 is:

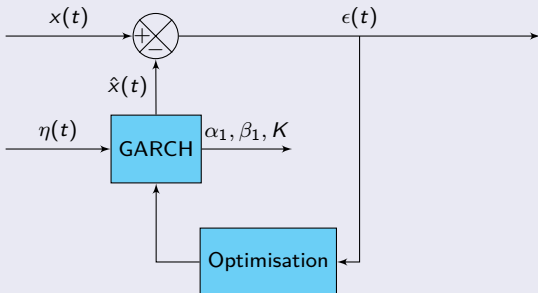
$$\hat{\sigma}^2(n) = K + \sum_{i=1}^p \alpha_i x^2(n-i) + \sum_{j=1}^q \beta_j \sigma^2(n-j) \quad (5)$$

where α_i and β_j are the GARCH parameters, p and q are the orders of the model. As a GARCH(1,1) is sufficient to detect micro-emboli, the DI proposed were:

$$DI_4(k) = \max (K(k))|_k,$$

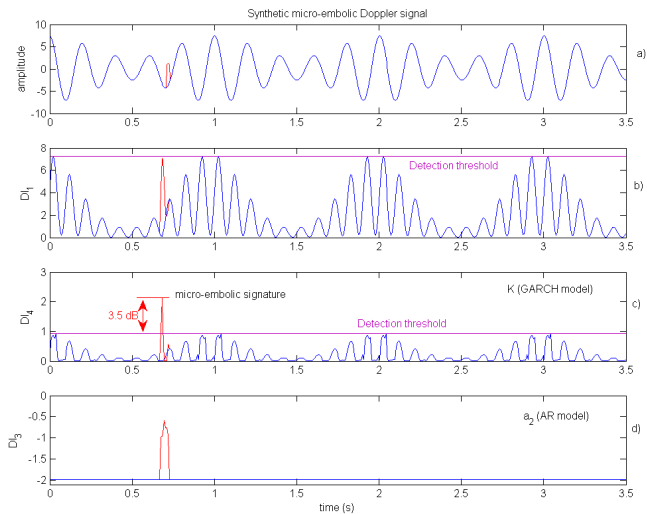
$$DI_5(k) = \max (\alpha_1(k))|_k.$$

$$DI_6(k) = \max (\beta(k))|_k.$$



Results

Synthetic micro-embolic Doppler signals: Results



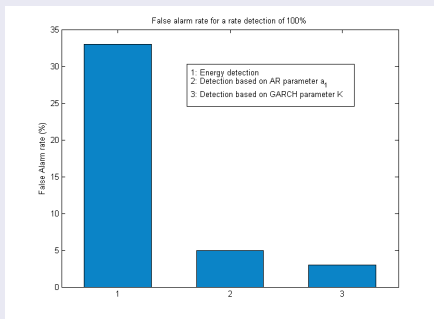
Synthetic micro-embolic Doppler signals: Results

- Micro-embolic energy was set to do not trigger the standard energy detector;
- For the detector based on the AR parameters, DI_3 is the best parameter;
- For the detector based on the GARCH parameters, DI_4 is the best parameter;

Synthetic micro-embolic Doppler signals: Discussion

- The good performances of the GARCH parameters detector confirm the fact that the GARCH model is well adapted to model the ultrasonic Doppler energy variations;
- The dynamic of DI_3 was better than the dynamic of DI_4 , involving a reduced false alarm rate. This result suggests us to use the AR parameters detector.

In vivo study: Results



Detector performances (False alarm rate).

For a detection rate of 100%,

- Standard energy detector (DI_1): the false alarm rate was of 33%;
- AR parameter detector (DI_3): the false alarm rate was of 5%;
- GARCH parameter detector (DI_4): the false alarm rate was of 3%;

Discussion

In vivo study: Discussion

The detector performances obtained *In vivo* corroborate the simulated study:

- The standard energy detector DI_1 has poor performances;
- the AR parameter detector DI_4 has very good performances;
- the GARCH parameter detector DI_4 has very good performances.

The performances of the GARCH parameters detector exceeds the performances of the AR parameter detector. This can be explained by the fact that:

- AR parameters are both sensitive to frequency and energy variations involving false alarms coming from frequency variations and energy variations;
- GARCH parameters are sensitive only to energy variations involving false alarms coming from only energy variations;

Conclusion

Conclusion

- We have tested and compared different micro-emboli detectors;
- Parameters detector were by far better than standard energy detector;
- The very good performances of the GARCH parameter detector are very promising for an one-line algorithm implementation in a commercial TCD system.