DISCRIMINATION BETWEEN EMBOLI AND ARTIFACTS DURING TRANSCRANIAL DOPPLER

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Abstract

Cerebral Vascular accidents remain one of major causes of die and handicap the most frequently met in occidental countries. These ones are often associated to emboli transit, foreign bodies to blood normal composition, in cerebral circulation. Emboli number, nature are also directly related to a pathological degree. It seems obvious that a good emboli detection needs rejection of artifacts, which are undesirable events. The aim of this work is to proceed different artifact Doppler signals and to introduce *a priori* and *a posteriori* parameters which are able to characterize them at best. We discuss about their reliability for artifact rejection.

Introduction

Cerebral Vascular accidents and particularly cerebral embolisms represent more than two third of all ischemic strokes. Indeed, several insoluble bodies (fat, red cells aggregation, clots ...) foreign to blood composition, called emboli, can move into intracranial arteries. Since several years, TransCranial Doppler ultrasound (TCD) systems have been the most used techniques in counting and detecting emboli. The number of emboli events stored and detected can be established as a good indicator of stroke risks considering that it is associated to a particular vascular pathology. In order to improve therapeutic following, a best sensitivity in detection and classification emboli is hoped. Several detection methods especially for micro-emboli have been investigated[1]. Moreover, artifacts, events totally independent to emboli transit in blood flow, can be identified as emboli occurrences and thus deluded their counting. In practical use, one supposed that artifacts are bidirectional, mainly provoked by backward and forward probe displacement in blood Doppler spectrum. They occurred simultaneously at each depth[2], if a multigate in-phase and quadrature demodulation Doppler Pulsed Wave (PW) system is used. These criteria being almost subjective, we have established a panel of significant parameters. We'll describe firstly a corpus including the most met artifacts in clinical situation. Then, different parameters obtained with two sample gates or two insonification frequencies are investigated. The results of this investigation will be discussed in the following section.

Artifacts analysis

Corpus Establishment

We have created an artifacts corpus covering the most met clinical situations. These ones were acquired using to two ATYS medical devices: a 2 MHz two sample gates PW system and a two emission frequencies 1.66 and 2.5 MHz PW one. The sample volume is located in the middle cerebral artery at a depth of 46 mm, with a gate of 4 mm and a 100 $mW.cm^{-2}$ emission power. This set-up has been conserved at best, specially insonification angle for all the different types of artifacts, which are: probe tapping, speak, sneeze, cough, sigh, gnashing, laugh, sniff, wink, yawn.

Signals analysis and parameter extraction

The first investigations were performed with a single emission frequency. The signals have been, thus, proceeded off-line and frequency, energy, and duration parameters were computed. Concerning frequency parameters, we compute three estimators (modal, centroid, and maximal frequencies).

For this, consider the spectrum S(f) obtained on a 25 ms temporal window around artifact occurrence. Modal f_{mod}, centroid f_c, and maximal f_{max} are, respectively, given by the expressions (1),(2), and (3) and relevant results are shown on figures (1),(2),(3). These figures show the (above) frequency estimators values with corresponding standard deviations, for each artifact type, estimated using the two signals obtain in the two sample volumes.

$$f_{mod} = argmax_f(S(f)) \tag{1}$$

$$f_c = \frac{\int_0^{\frac{f_e}{2}} fS(f)df}{\int_0^{\frac{f_e}{2}} S(f)df} \tag{2}$$

$$f_{max} = fc + B/2 \tag{3}$$

f_e is the sampling frequency, and B is the $-6dB$ bandwidth.

We can remark that modal and centroid frequencies means (figure 1 and figure 2) are confined in the same range (100-250 Hz), but centroid frequencies values have highest standard deviations. Maximal frequencies (figure 3) can reach about 650 Hz, with important standard deviations between each artifacts type. Moreover, these frequencies are independent of artifact occurrence

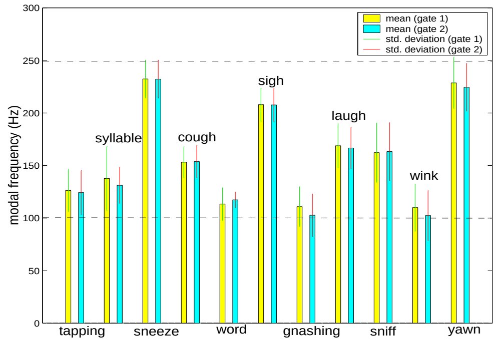

Figure 1: Modal frequencies.

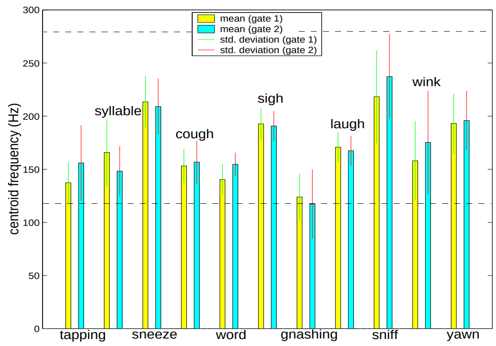

Figure 2: Centroid frequencies.

in cardiac cycle (diastolic or systolic times) and, specially the modal ones have very low values unlike emboli supposed to travel at the red blood cells (RBC) background speed. The results of the two gates are similar in terms of these estimators.

Concerning energy parameters, we introduced two estimators called ANR (Artifact to Noise Ratio) and ABR (Artifact to Blood Ratio). These ones can be expressed by equations(4),(5).

$$ANR = 10log_{10}(\frac{P_{art}}{P_{noise}}) \qquad (4)$$

$$ABR = 10log_{10}(\frac{P_{art}}{P_{blood}}) \qquad (5)$$

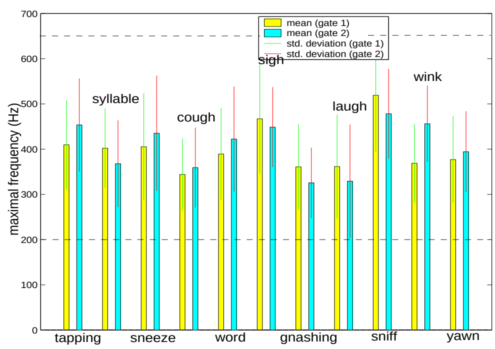

Figure 3: Maximal frequencies.

It can be noticed in figure(4) that ANR values are between 30 and 62 dB ; indeed this criteria is essentially based on the bidirectional property of almost artifacts. ABR values, figure(5), are confined between 17 and 35 dB. These last ones can be compared to EBR (Embolus to Blood powers Ratio)[3]. These values are at far greater than the ones found, when micro-emboli are encountered.

Finally, we computed a duration-like parameter. For

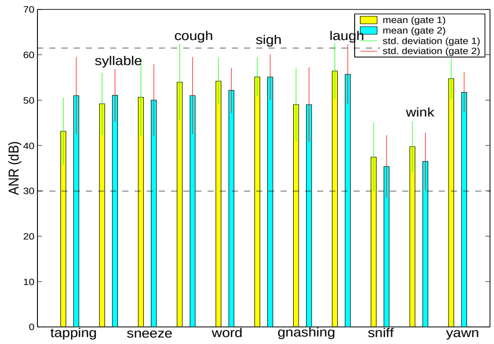

Figure 4: ANR values.

Figure 5: ABR values.

this, sample volume length (SVL)[4] values are used, and are expressed by equation(6). v_{max} is related to f_{mod} (equation 1) via well-known Doppler frequency expression with a 0^o angle. In fact, the artifact event is assumed to behave like emboli. If this assumption is correct, SVL should be close to the sample volume length chosen by the user, ie $\simeq$ 4mm.

$$SVL_{max} = \tau.v_{max} \qquad (6)$$

τ is event duration. In case of a moving embolus, SVL is defined as an effective sample volume length, which is directly function of embolus transit time and its associated speed. Embolus transit time is included between 10 and 200 ms with a 4mm gate and with a speed range from 0.02 to 0.4 $m.s^{-1}$. We can see, in figure(6), that SVL means can reach 90 mm for sigh or speaking, which are no more related to physical features. However, in case of probe tapping or gnashing, SVL means

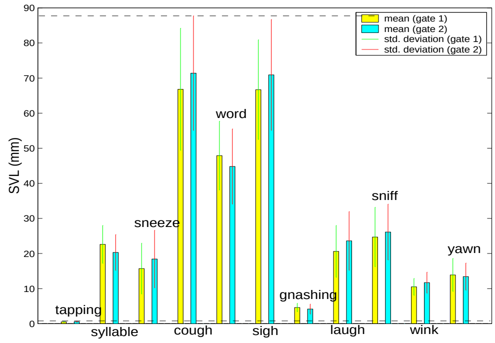

Figure 6: Sample Volume Lengths.

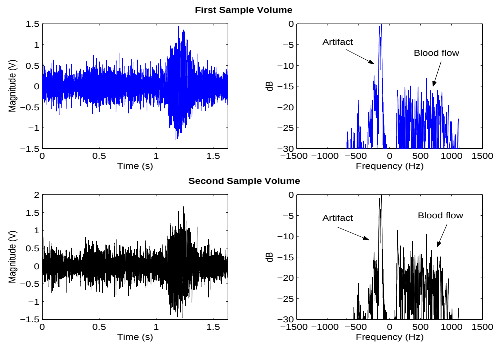

Figure 8: Temporal signal and spectral contents of an unidirectional laugh artifact.

are around 4mm. The sample volumes used were two gates distant of one gate, so we can determine, for each artifact types, time delays between their occurrences in proximal and distal gates. Maximal and minimal values obtained are shown in the figure(7). These values

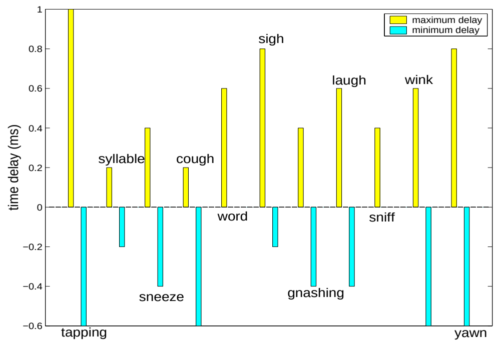

Figure 7: Time delays.

don't exceed at best 1 ms, whereas they are, in case of emboli, confined between 10 and 350 ms in our experimental condition. This time delay estimator could thus be an interesting parameter for artifact rejection. Nevertheless, it may be erroneous in case of multiple emboli, or when the sample gates are short compared to embolus velocity.

Observations

Usually people dealing with emboli detection assume that all artifacts are bidirectional in Doppler spectrum. We can show in figure(8) that it isn't always true. This may be explained as follows. It is known that RF backscattered signal is a mixing of the component reflected by immobile tissus(which is the DC component after demodulation), the one backscattered by RBC's moving, and finally the one associated to vessel walls motion. In normal conditions, after in-phase and quadrature demodulation and high-pass filtering, it remains only Doppler spectrum caused by RBC's transit. Artifact apparitions induce frequency transposition of each components of the whole RF spectrum. This is be due to stationary media put in moving by probe's relative displacement. Figures (9) and (10) detailed several cases met following probe's displacement direction.

Figure(9) is a typical case of a bidirectional artifact

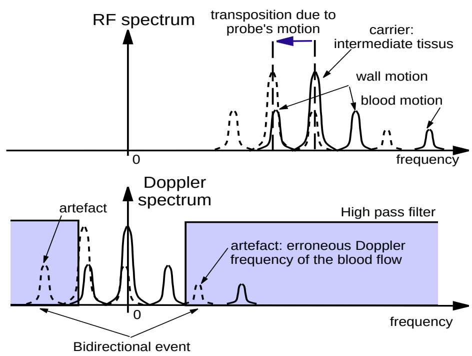

Figure 9: Frequency transposition of the Doppler spectrum: bidirectional artifact.

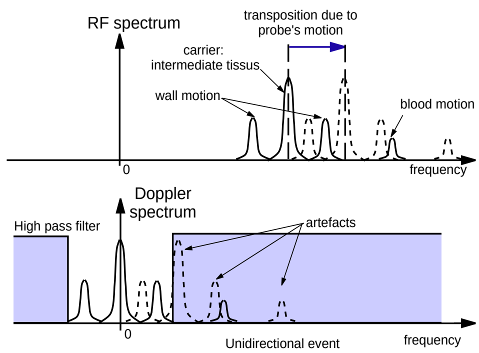

Figure 10: Frequency transposition of the Doppler spectrum: undirectional artifact.

event. Probe displacement is in a backward sense of blood flow. We can observe that all RF spectrum frequencies components are transposed. The high-pass filter doesn't eliminate any more negative frequency components of wall motion. Figure(10) shows, this time, a case of a forward sense probe's displacement. Frequency components are transposed positively. It can be remarked that frequency components due to intermediate tissus or wall motion are always here in Doppler spectrum after demodulation and high-pass filtering. All these components have positive values, and are in forward flow. It is clearly an unidirectional artifact situation.

Signals analysis with the two emission frequencies device

The artifacts corpus is the same as previously, excepted it was acquired with the two emission frequencies 1.66 MHz and 2.5 MHz device. We compute a modal frequencies ratio as follows.

$$R = \frac{f_{mod_{1.66MHz}}}{f_{mod_{2.5MHz}}} \tag{7}$$

In case of an embolus crossing in sample volume, we could recover the same ratio that emission frequencies one, so $\frac{2}{3}$. We computed this ratio for artifact events. In figure(11), it can be noticed that we don't have any more the same ratio, and moreover this ratio tends to 1 for each type of artifact. It seems that these frequencies are independent of emission frequency. Therefore, this is due to the fact that the probe movement is asynchronous and depends only on the probe's speed. Artifacts may be observed even in absence of scatterers movement or in presence of 90^o Doppler angle. Deeper investigations of this phenomenon is now being carrying on.

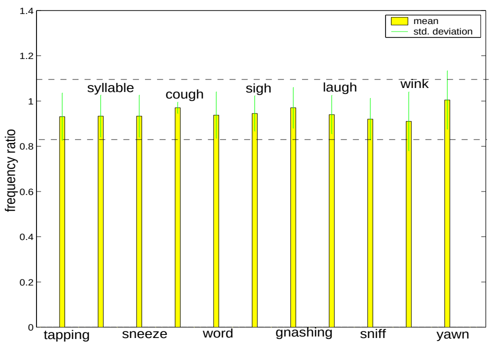

Figure 11: Modal frequencies ratio.

Discussion

We have reviewed several frequency, energy, temporal parameters in order to characterize artifact signatures in Doppler signal. Reliable parameters are mainly modal frequencies, which are very low and independent of cardiac cycle time, SVL and ABR. In combining these ones, it could be possible to obtain a reliable artifact rejection without necessary use a multigate system. We have seen that *a priori* artifacts rejection based to the bidirectionality of the signal can be wrong. In case of use of a two emission frequencies PW system, a reliable artifact rejection can be reached in performing modal artifact frequencies ratio.

References

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