Optimal Kernels Application to Improve Late Ventricular Activity Detection
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ABSTRACT

Sometimes when a myocardium infarct occurs, small abnormalities in conduction are present over the infarcted zone. These components are known as Ventricular Late Potentials (VLP) and are associated with ventricular arrhythmias and sudden cardiac death. They are components of ventricular conduction activity that are attenuated, fragmented and delayed over the QRS complex of an electrocardiogram (ECG). VLP are often used as non-invasive markers of arrhythmia risk and while their detection is difficult, there are non-invasive methods proposed for improved detection. The classical time domain method is the most often used for VLP detection in the analysis of high resolution ECG (HRECG) on post-infarction patients. Nonetheless, it brings low predictive values, high sensitivity to noise and excludes in its analysis patients with bundle branch blockage. In this paper the different morphologies of VLP are used for deducing a bi-dimensional Kernel in the time-frequency domain, so that it can be adapted to changing VLP structures according to each post-infarct patient. Also, both the reduction of false negatives and an increase in true positives of the automatic diagnosis can be achieved. A database of 132 HRECG signals was analyzed and a substantial increase in predictive values was obtained over diagnostics. In the analysis, attenuated sensitivity to noise compared to the classical temporal domain method was also shown.

Key Words:
Ventricular Late Potentials, High Resolution ECG, Time-Frequency Analysis, Dependent Kernel, Post-Infarction, SAECG.

RESUMEN

Después de que ocurre un infarto de miocardio, a veces se presentan pequeñas anomalidades de conducción sobre la zona infartada. A estos componentes se les llama potenciales tardíos ventriculares (VLP), y se les asocia con las arritmias ventriculares y muerte cardiaca súbita. Son componentes en la actividad de conducción ventricular que se atenuan, se fragmentan y se retrasan sobre el complejo QRS del ECG. Los VLP son muy usados como marcadores no invasivos de riesgo arrítmico, y aunque su detección es muy difícil, existen propuestas de métodos no invasivos para mejorarla. El método del dominio temporal clásico es el más utilizado para la detección de VLP, en el análisis de señales ECG de alta resolución (HRECG) de pacientes post-infarctados. Sin em-
INTRODUCTION

In the event of survival to a myocardium infarct, the zone of affected cardiac tissue can produce in most cases malign arrhythmia, being the most dangerous those located at the ventricles because of their ability to produce sustained ventricular tachycardia and/or ventricular fibrillation and consequently bring sudden death.

Malignant ventricular tachycardia is a pathology present in a great number of patients who are in a partial myocardium infarct recovery process. From these events a great interest is born in many scientist and researchers to study new effective prediction techniques for ventricular tachycardia risk factors that may permit a cardiologist to prevent sudden death in post-infected patient.

The most effective methods to date are invasive in nature, so they are inconvenient for requiring surgery to the patients. To avoid risk factors brought by surgery, some researchers have proposed the use of some electrophysiological characteristics that behave as arrhythmia risk flags for the development of non-invasive methods of sudden cardiac death.

The tissue zone damaged by an infarct goes through a physiological process in a healing effort. In any event, the tissue makes a partial recuperation and its effects carry in many cases lethal consequences because part of the electrical activity originated from the cardiac depolarization wave front suffers attenuation, fragmentations and time lag, bringing malignant ventricular tachycardia. These irregularities in ventricular conduction have been denominated ventricular late potentials (VLP), and can be registered by superficial techniques of electrocardiography (ECG) known as high resolution ECG (HRECG).

HRECG are used with much frequency by most non-invasive methods mentioned in literature, such as time domain, frequency domain, spectro-temporal, and others. The most accepted but also standardized method for detecting VLP is the time domain, known as classic time domain method. Unfortunately, it gives low predictive values and post-infarcted patients with branch blockage must be excluded from analysis.

As time progresses, it is known of more research being made with the objective of refining VLP detection and analysis where techniques as complex as time-frequency representations, and wavelet transform are used. All these search one common objective, to raise the predictive values of automated diagnosis. Perhaps the wavelet transform is one of the techniques to have brought best results in VLP detection. On the other hand, in all these proposals there is a lack of normalization and standardization regarding their ventricular conduction abnormality criteria, for such a reason, varied results are currently being generated.

METHODOLOGY

The structural morphology of VLP varies from patient to patient, because it depends on the type and age of the infarct, it also depends on the patients genetic and physiological characteristics. These morphologic variations and its noise sensibility are some of the elements generating false positive and false negative VLP detection. In Figure 1...
are shown twelve VLP taken over the epicardic infarcted zone, where it is easy to notice differences between each other.

This paper proposes a technique applying kernel design for time-frequency analysis such that a kernel may be adapted in an optimal manner to the VLP changing structural characteristics present into a particular HRECG.

### KERNEL FUNCTIONS

The ambiguity function (AF), is a bidimensional function, related to the wigner distribution (WD), it is obtained by the following mathematical procedure:

\[
AF(\theta, \tau) = \int \int WD(t, f) e^{-2\pi i (\theta t - \tau f)} dt df,
\]

Where:

\[
WD(t, f) = x(t + \frac{\tau}{2})^* e^{\pi i \theta f} e^{-\pi i \tau f} dt.
\]

Both WD and AF produce non-desirable artifacts over a time-frequency domain, which are called interference terms. These artifacts can be attenuated by means of bidimensional filters, known as kernel functions (KF).

KF work as low pass filters over the AF in a bidimensional domain as follows:

A time-frequency representation (TFR) is a member of the Cohen class, if and only if it can be deduced from a WD convolution a KF, i.e.:

A TFR ∈ Cohen Class \iff

\[
TFR((t, f) = \int \int WD(t', f) \psi_{TP}(t - t', f - f') dt' df',
\]

Where: \( \psi \) is a KF in the time-frequency plane.

This convolution can be a simple multiplication if it is taken to a frequency domain by means of the bidimensional Fourier transform, this way we have:

\[
TFR((t, f) = \int \int AF((t', f') \phi_{TP}(t, f') e^{2\pi i (\theta t - \tau f')} dt' df',
\]

where: \( \phi \) is the Kernel Function on the correlative plane to the time-frequency plane.

If the AF interference terms are concentrated out from the origin, and the signal terms are over and near the origin on the plane, then a multiplication with the KF will produce cancellation of some cross terms and others will only be attenuated.

When the KF design is not dependent from the signal, disturbance and distortions are produced over some signal terms on the time-frequency plane. To avoid this, some authors propose the use of optimal kernel functions, also known as signal dependent kermels, because both their form and volume are adapted to the form and volume of the signal terms over the bidimensional domain that the AF generates.

### KERNEL FUNCTION APPLICATION ON HRECG

If we consider that a TFR may be obtained using an inverse bidimensional Fourier transform (2DFT) from

![Figure 1](image1.png)

**Figure 1.** VLP taken from different patients. (a), (b) and (c) registered 5 days after infarct event, (d) and (g) taken 2 weeks after infarct event, (h), (k) and (l) taken 2 months after infarct event, (e), (f), (i) and (j) taken 6 months after infarct event (from Gardner P. et al. Electrophysiologic and anatomic basis for fractionated electrocardiograms recorded from healed myocardial infarcts. Circulation. 1985;72:596-611. Figure taken with permission of Kluwer Academic Publisher. Ref: Gomes, Signal Averaged Electrocardiography, pp.19, figure 6, 1993).

![Figure 2](image2.png)

**Figure 2.** (a) HRECG taken from a clinically diagnosed patient without risk of arrhythmia, and low pass filtered at 25 Hz cut frequency, (b) VLP similar to that shown in figure 1(A) (out of scale), (c) HRECG signal product of sum from (a) and (b), (d) VLP similar to that shown in figure 1(L)(out of scale), (e) HRECG signal product of sum from (a) and (d). All VLP have an amplitude below 25\(\mu\)V, HRECG have an amplitude between 1.5 and 2\(m\)V.
The product of the AF with the KF from the analyzed signal: \( RTF = (AF)(KF) \), then it is possible to state that the most adequate KF will be the one adapting to the VLP signal terms over the time-frequency plane.

In order to detect VLP, we will use optimal Gaussian Kernel types (ORGK)\(^2\). In Figures 2(a) and 2(d), is shown the same HRECG signal, taken from a patient whom has been clinically diagnosed not to have risk of arrhythmia. This signal was low pass filtered at 25Hz with the objective of adding VLP shown in Figure 2(b) and 2(e), respectively. The results of summation for each case are illustrated in Figures 2(c) and 2(f).

The VLP ORGK is extracted and shown in Figure 2(b), consequently an inverse 2DFT is calculated, from the product of ORGK with the AF taken from the HRECG signal shown in Figure 2(c), the TFR is generated from Figure 4(c). The ORGK, the AF and the product of both time-frequency planes are shown in Figures 3(c, d, and e), respectively.

We can appreciate the localization of VLP in a time-frequency plane as illustrated in Figure 4(c), when the AF is multiplied by the ORGK, obtained from the same VLP added to the HRECG signal (see Figure 3). When the ORGK is obtained from the VLP shown in Figure 5(b), the temporal localization in a time-frequency plane shown in Figure 2(f), 5(a) ó 4(e), is not as effective as expected. Again, this result is because the ORGK obtained from the VLP shown in Figure 3(b), permit to pass less HRECG signal terms than the ORGK gotten from the VLP that were added to the HRECG (see Figure 5(b)).

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Now, if VLP of Figure 2(e) are added to the HRECG signal of Figure 2(d), the HRECG signal of Figure 2(f) is achieved. As can be seen, just like in the previous case, VLP can not be seen with the naked eye in the HRECG signal. Once again, if the AF of the HRECG is multiplied by the ORGK of the VLP (see Figure 5), and the inverse 2DFT is obtained, it yields the time-frequency representation of Figure 6(c). The time-frequency representation of Figure 6(f) is obtained using the previous procedure, but with the use of ORGK from Figure 3(d) obtained by VLP from Figure 3(b). As can be seen, VLP detection is substantially increased using ORGK as in Figure 3(d), due to the filtering of excessive signal components because of the ORGK adaptation to the VLP signal representation over its AF.

RESULTS

A database of 132 HRECG signals was analyzed, and organized in the following categories:

LAR Group (No infarct to the myocardium, under risk of ventricular tachycardia). Built from 73 HRECG signals taken from post-infarcted patients. These patients were treated at the Veterans Affairs Medical Center in Oklahoma City, where an electrophysiological study was done after having survived a myocardium infarct.

VT Group (myocardium infarct with ventricular tachycardia risk). Built from 59 HRECG signals taken from post-infarcted patients. These patients were treated at the veterans Affairs Medical Center in Oklahoma City, where an electrophysiological study was done after having survived a myocardium infarct.

Table 1. Predictive values achieved through the classic time domain method (QRSd = QRS duration), and with the optimal radial Gaussian kernel method (ORGK-VLP).

<table>
<thead>
<tr>
<th>Method</th>
<th>LAR Group</th>
<th>VT Group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 73)</td>
<td>(n = 59)</td>
<td>(n = 132)</td>
</tr>
<tr>
<td></td>
<td>PF</td>
<td>NV</td>
<td>NF</td>
</tr>
<tr>
<td>ORGK-VLP</td>
<td>9</td>
<td>64</td>
<td>7</td>
</tr>
<tr>
<td>QRSd</td>
<td>11</td>
<td>62</td>
<td>10</td>
</tr>
</tbody>
</table>

PF = false positives, NV = true negatives, NF = false negatives, DET = correctly detected cases.

DISCUSSION

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The predictive values obtained with this analysis were superior to those given by the classic time-domain analysis; regardless, to establish an abnormality criterion with the proposed techniques, there remains a need to develop an automated quantification method of ventricular abnormality, while the results shown in this paper are evaluated over a visual type analysis.

CONCLUSIONS

With the results achieved from analysis of the database, it has been shown that with the application of these techniques in the analysis of HRECG, it's
possible to detect late ventricular activity in post-infarcted patients.

There is a need to test a great number of cases with a new database in order to compare results from analysis and have more judgment elements regarding the benefits of the method proposed.

REFERENCES