



Engineering Medical Research



Sparse Representation of ECG Signals Using Over-complete dictionaries for Physiological Analysis







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- While temperature, pulse, respirations, and blood pressure are all objectively measure; <u>pain is</u> <u>inherently subjective</u>.
- failure to properly assess pain is a common cause of its poor control and lack of treatment in patients in different settings
- It has been termed "the fifth vital sign" and is now being evaluated and registered in the patients' charts during routine checkups.



Medical Background

- Studies on <u>skin conductance and heart rate</u> shoewd these markers were found to be <u>non specific to pain.</u>
- More sophisticated measurement like <u>biomarkers</u> for pain intensity and <u>EEG analysis</u> have been tested but were found <u>non</u> <u>applicable</u>.
- To date, <u>no clinically applicable tool has been developed to use</u> <u>the HRV to assess pain levels accurately in patients</u>.
- Moreover, several studies, including those involving neonates, have established that this system was unable to serve as a sole objective pain assessment tool.



Our objective is to find correlation between the ECG and the Heart rate to pain by novel analysis methods







Points of interest for advanced analysis

















-2000

Window Size

15000

10000 ECG 5000

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71.5

5

71.5

72

72 72.5

Set Limit

72.5

73

73

73.5

Zoom

73.5

74

74

74.5

Close

74.5

75

75

75.5

75.5

Mean RR

76

76

Identifying the R waves

ECG Analysis

• Forming the R-R wave



Why bother? - HRV for Pain Analysis

🥟 heart rate variability pain - PubMed result - Windows Internet Explorer							
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 Exploring non-invasive methods to assess pain in sheep. Stubsjøen SM, Flø AS, Moe RO, Janczak AM, Skjerve E, Valle PS, Zanella AJ. Physiol Behav. 2009 Oct 13. [Epub ahead of print] PMID: 19833144 [PubMed - as supplied by publisher] Related articles 							

Fourier Transform

- The Fourier transform (FT) is an operation that transforms one complex-valued function of a real variable into another.
- That of the new function is frequency, and so the Fourier transform is often called the frequency domain *representation* of the original function.
- The Fourier transform decomposes a function of time (a signal) into the frequencies that make it up

Fourier Transforms





The Wavelet Transform

- A wavelet series is a representation of a square integrable (real - or complex - valued) function by a certain orthonomal series generated by a fixed and known pattern known as a wavelet.
- Unlike FT, the continuous wavelet transform possesses the ability to construct a time-frequency representation of a signal that offers very good time and frequency localization.

The Wavelet Transform

• The Haar Wavelet





The Wavelet Transform





• Fourier Transforms – signal Harmonics

• <u>Wavelets</u> time dependant acute change

Orthogonal Matching Pursuit

- OMP is a greedy least-squares procedure that chooses the dictionary vectors one at a time.
- At each step (k=1) a single vector from the combined dictionary that has the highest correlation with b is chosen by solving the following problem:

$$\begin{split} \min_{v} \left(\min_{c} \|b - cv\|_{2} \right) \\ v \text{ is a vector of the matrix } [A_{1} | A_{2}] \text{ and } c \in R \\ \hat{b}_{1} \text{ be the resulting best approximation of } b \\ e_{1} &= b - \hat{b}_{1} \text{ be the error after the first step} \\ \text{ In the } k \text{-th step the next vector is determined by solving} \\ \min_{v} \left(\min_{c} \|e_{k-1} - cv\|_{2} \right) \\ v \text{ is a vector of the matrix } [A_{1} | A_{2}] \text{ and } c \in R \end{split}$$

The Cold Pressor Experiment

- 15 healthy adult volunteers participated in this experiment.
- The subjects were sampled during 10 minutes of rest as baseline. Then they dipped their dominant hand into icy water to produce acute pain and each subject kept the hand till the point of maximal pain and voluntarily took the hand out.
- Sampling ended when the subject was relieved of any pain













Only Wavelets















Only Wavelets



200 250 300 350

400 450 500

0.4

150









	Standard Wavelet Transform coefficients density					OMP Wavelet coefficients density				
	(coefficients per seconds)				(coefficients per seconds)					
Subject	Baseline	Incline	Stable	Decline	Σ СРТ	Baseline	Incline	Stable	Decline	Σ СРТ
	10/398	11/91	2/31	10/159	23/281	1/398	5/91		5/159	10/281
1	(0.025)	(0.12)	(0.064)	(0.0629)	(0.0818)	(0.0025)	(0.055)		(0.0314)	(0.0355)
	12/414	5/105	1/100	13/335	19/540	1/414	3/105		3/335	6/540
2	(0.0289)	(0.0476)	(0.01)	(0.0388)	(0.0351)	(0.0024)	(0.028)		(0.0089)	(0.0111)
	12/60	22/108			22/108	2/260	16/108			16/108
3	(0.2)	(0.203)			(0.203)	(0.0077)	(0.148)			(0.148)
	3/482	4/198	6/113	4/240	14/551	2/482	1/198	3/113	3/240	7/551
4	(0.0062)	(0.0202)	(0.053)	(0.0156)	(0.0254)	(0.0041)	(0.005)	(0.0265)	(0.0125)	(0.0127)
	7/328	5/93	2/98	7/205	14/396	4/328	2/93		8/205	10/396
5	(0.0213)	(0.0537)	(0.0204)	(0.0341)	(0.0353)	(0.0121)	(0.0215)		(0.039)	(0.0252)
	13/346	10/139			10/139	1/346	3/139			3/139
6	(0.0375)	(0.072)			(0.072)	(0.0029)	(0.0216)			(0.0216)
	4/397	3/98	23/287		26/385	2/397	1/98	6/287		7/385
7	(0.01)	(0.03)	(0.08)		(0.0675)	(0.005)	(0.0102)	(0.0209)		(0.0182)
	2/425	3/191	6/412		9/603	1/425	3/191	5/412		8/603
8	(0.0047)	(0.015)	(0.0145)		(0.015)	(0.0024)	(0.0157)	(0.0121)		(0.0132)
	12/258	6/142	4/135	11/308	21/585	1/258	3/142	1/135	2/308	6/585
9	(0.0465)	(0.0422)	(0.0296)	(0.035)	(0.0358)	(0.0039)	(0.211)	(0.0074)	(0.0065)	(0.0102)
	17/328	4/115	9/360	10/120	23/783	4/328		4/360	6/120	10/783
10	(0.0518)	(0.0347)	(0.025)	(0.083)	(0.0293)	(0.0121)		(0.011)	(0.05)	(0.0128)
	13/291	5/89			5/89	2/291	3/89			3/89
11	(0.0446)	(0.0561)			(0.0561)	(0.0069)	(0.0337)			(0.0337)

<u>Results</u>

- Data from 11 subjects was analyzed.
- Compared to baseline, The WT analysis showed a significant coefficients density increase during the pain incline period (p<0.01) and the entire CPT (p<0.01), with significantly higher coefficient amplitudes.
- The OMP analysis showed a significant wavelet coefficients density increase during pain incline and decline periods (p<0.01, p<0.05) and the entire CPT (p<0.001), with suggestive higher amplitudes.
- Comparison of both methods showed that during the baseline there was a significant reduction of wavelet coefficient density using the OMP algorithm (p<0.001).
- Analysis by the two way ANOVA with repeated measures showed a significant proportional increase of wavelet coefficients during the incline period and the entire CPT using the OMP algorithm (p<0.01).

Experiment #2

- UCSD VA
 Anasthesia
 department
 Pain research
- Controlled pain was inflicted on 15 subjects by capsaicin injection to the right thigh during ECG sampling, correlated to blood cortisol and substance P levels.















Only Fourier - Sliding window



Only Wavelet

















Conclusions

- HRV is personal dependant
- WT Suggestive
- OMP best representation

But.... This is not all.....

Arrhythmia Prediction

 Initial assessment: RR intervals from patients who experienced <u>ventricular arrhythmias</u> were made public by Medtronic Inc. on the Web (the Physionet database).

 Those patients' data were analyzed using the Wavelet transform and the OMP algorithm with an overcomplete Fourier/Wavelet dictionary

<u>Combined baseline and pre-arrhythmia</u> <u>signals</u>









Only WT



















Large Scale ECG Database.

- Data of 30 ICD patients with ventricular tachyarrhythmia from the HAWAI registry (Biotronik Ltd) was analyzed.
- HAWAI: assessment of HRV characteristics prior to the onset of VT/VF. Most had ischemic HD, all had Biotronik ICDs with extended memory function
- Each pt had >1 baseline file and several pre-shock files.
- The database included 36 baseline files and 83 pre-shock files, which were grouped together regardless of the individual patient.

Each file was about 30 minutes long. For each baseline file, three 10 minute long segments were extracted For each pre-shock period only the 10 minute segment prior to shock was used.

Using this model, <u>100 different baseline examples</u> and <u>83 pre-</u> <u>shock examples</u> were utilized.

Analysis Method

The System used a large matrix using several mathematical transforms combined to create the sparse representation of the tachogram:

The conventional Fourier transform

Short time Fourier analysis at different sliding scales

The Wavelet transform

Heart rate linear trends





Signal processing

- A discriminator was computed using ECG signal processing. An R-R signal was extracted from each sampled segment.
- For each sample the R-R signal was analyzed by using the OMP algorithm with an over-complete Fourier, Wavelet and other dictionaries
- Analysis included extraction of the energy and features of the calculated coefficients (e.g. number of wavelet coefficients, linear trend properties etc), and a classifier using logistic regression was used to discriminate between baseline and pre-arrhythmia examples.
 - 70 percent of the data was used for training the discriminator algorithm and 30 percent was used for testing.

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• The process was repeated 3 times and an ROC curve based on the percentage of recognition and the percentage of false positive recognition was built.

The ROC Curve



Results

Correct tachyarrhythmia prediction	False positive
78%	27%
87%	41%
90%	50%

Conclusions

An OMP-based discriminator achieved:

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- successful detection of a majority of the imminent shock periods
- with an inversely related false positive rate
- in a pooled, non-personalized data base with significant interpersonal clinical variations.
- We believe this initial analysis method for predictive tachyarrhythmia modeling can
 - be further improved to achieve clinically useful rates
 - suggest interventions to reduce VT/VF episodes and ICD shocks.
- Patient-specific tests are being performed to evaluate the current system.



- We believe this initial analysis method for predictive tachyarrhythmia modeling can be further studied in other systems.
- Our aim is to assess the pilots during the ROBD (reduced oxygen breathing device) and evaluate the ability of this system to predict physiological changes during hypoxia.

Questions ?

