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Wavelet Analysis of Biosignals: from Pretty Pictures to Product

Paul S Addison, PhD
Technical Fellow
Respiratory & Monitoring Solutions
Covidien
Scotland, UK

STA
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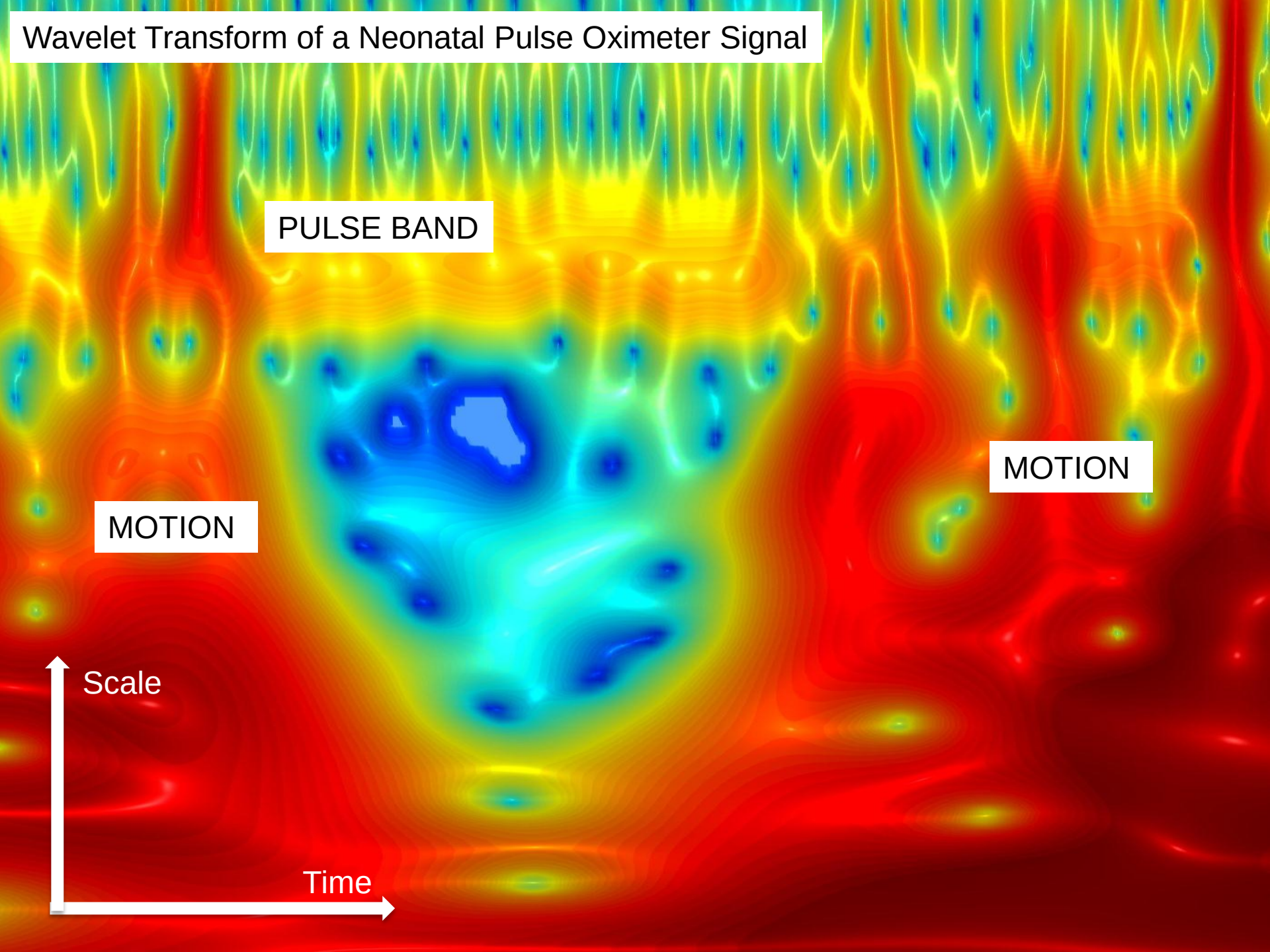
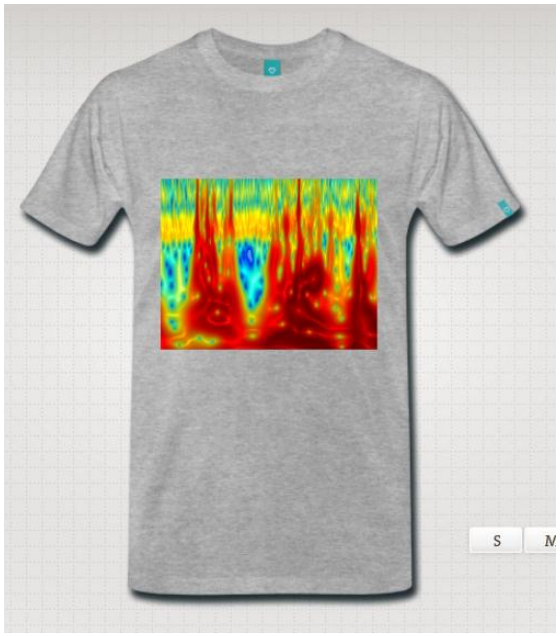
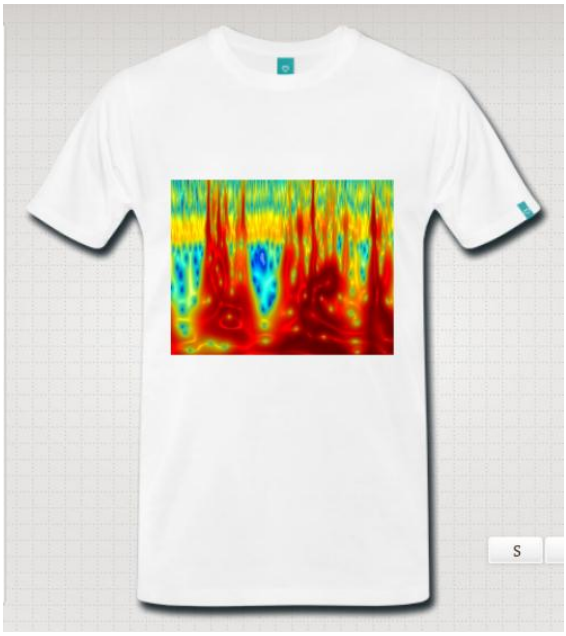

Wavelet Transform of a Neonatal Pulse Oximeter Signal
PULSE BAND
MOTION
MOTION
Scale
Time





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What are these pretty pictures?

… and why are they Important?

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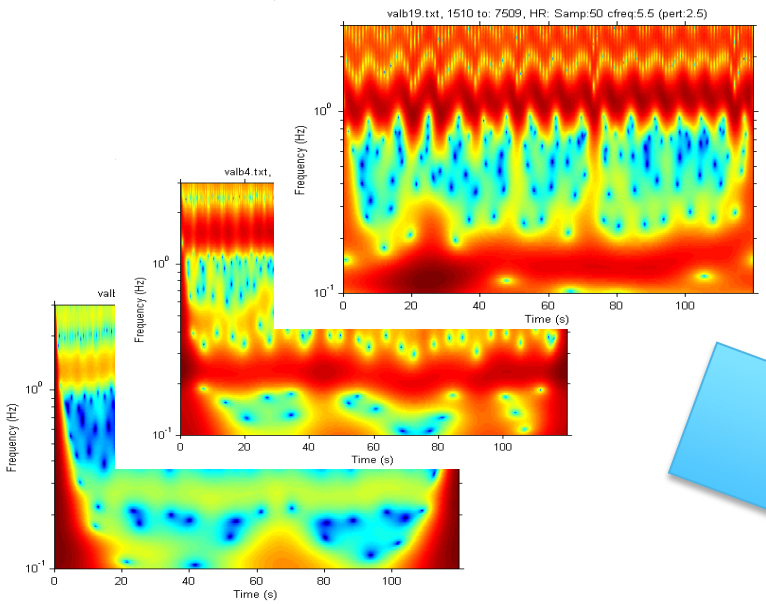
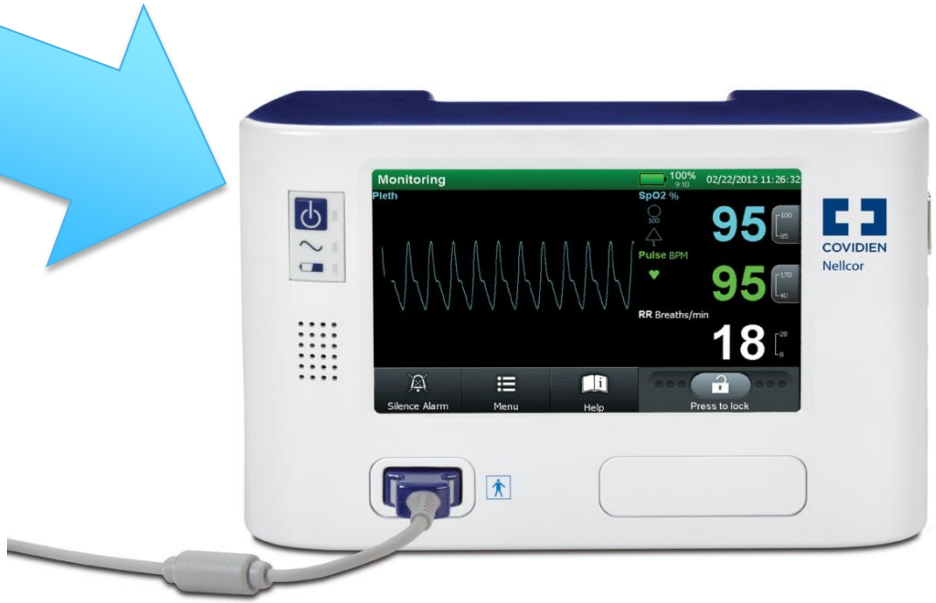
Analysis of Biosignals: from Pretty Pictures to Product





Math v Piccies

$$\int_{-\infty}^{\infty} \frac{\sqrt{a}}{\pi^{\left(\frac{1}{4}\right)}} \cdot \exp(2 \cdot i \cdot \pi \cdot f0 \cdot (t)) \cdot \exp\left[\frac{-1}{2} \cdot (t)^2\right] \cdot \cos(2 \cdot \pi \cdot f \cdot (a \cdot t + b))\, dt$$

$$\frac{a^{\left(\frac{1}{2}\right)}}{\pi^{\left(\frac{1}{4}\right)}} \cdot \int_{-\infty}^{\infty} 4 \cdot \exp(i \cdot \pi \cdot f0 \cdot t)^2 \cdot \exp\left(\frac{-1}{2} \cdot t^2\right) \cdot \cos(\pi \cdot f \cdot t \cdot a)^2 \cdot \cos(\pi \cdot f \cdot b)^2 - 2 \cdot \exp(i \cdot \pi \cdot f0 \cdot t)^2 \cdot \exp\left(\frac{-1}{2} \cdot t^2\right) \cdot \cos(\pi \cdot f \cdot t \cdot a)^2 - 2 \cdot \exp(i \cdot \pi \cdot f0 \cdot t)^2 \cdot \exp\left(\frac{-1}{2} \cdot t^2\right) \cdot \cos(\pi \cdot f \cdot b)^2 + \exp(i \cdot \pi \cdot f0 \cdot t)^2 \cdot \exp\left(\frac{-1}{2} \cdot t^2\right) - 4 \cdot \exp(i \cdot \pi \cdot f0 \cdot t)^2 \cdot \exp\left(\frac{-1}{2} \cdot t^2\right) \cdot \sin(\pi \cdot f \cdot t \cdot a) \cdot \cos(\pi \cdot f \cdot t \cdot a) \cdot \sin(\pi \cdot f \cdot b) \cdot \cos(\pi \cdot f \cdot b)\, dt$$

$$\frac{1}{2} \cdot a^{\left(\frac{1}{2}\right)} \cdot \pi^{\left(\frac{1}{4}\right)} \cdot \sqrt{2} \cdot \left[2 \cdot \exp\left[-2 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] \cdot \cos(\pi \cdot f \cdot b)^2 + 2 \cdot \exp\left[-2 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right] \cdot \cos(\pi \cdot f \cdot b)^2 - \exp\left[-2 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] - \exp\left[-2 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right] + 2 \cdot i \cdot \exp\left[-2 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] \cdot \cos(\pi \cdot f \cdot b) \cdot \sin(\pi \cdot f \cdot b) - 2 \cdot i \cdot \exp\left[-2 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right] \cdot \cos(\pi \cdot f \cdot b) \cdot \sin(\pi \cdot f \cdot b)\right]$$

$$\frac{1}{2} \cdot a^{\left(\frac{1}{2}\right)} \cdot \pi^{\left(\frac{1}{4}\right)} \cdot \sqrt{2} \cdot \frac{\left(2 \cdot \cos(\pi \cdot f \cdot b)^2 + 2 \cdot \exp\left(\pi^2 \cdot f \cdot a \cdot f0\right)^8 \cdot \cos(\pi \cdot f \cdot b)^2 - 1 - \exp\left(\pi^2 \cdot f \cdot a \cdot f0\right)^8 + 2 \cdot i \cdot \cos(\pi \cdot f \cdot b) \cdot \sin(\pi \cdot f \cdot b) - 2 \cdot i \cdot \exp\left(\pi^2 \cdot f \cdot a \cdot f0\right)^8 \cdot \cos(\pi \cdot f \cdot b) \cdot \sin(\pi \cdot f \cdot b)\right)}{\left(\exp\left(\pi^2 \cdot f^2 \cdot a^2\right)^2 \cdot \exp\left(\pi^2 \cdot f \cdot a \cdot f0\right)^4 \cdot \exp\left(\pi^2 \cdot f0^2\right)^2\right)}$$

Reduce components by hand using cos2x and exp identities as performed later on

$$2^{a^{\left(\frac{1}{2}\right)}} \cdot \pi^{\left(\frac{1}{4}\right)} \cdot \sqrt{2} \cdot \left[2 \cdot \exp\left[-2 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] \cdot \exp(\pi \cdot f \cdot b) \cdot \cos(\pi \cdot f \cdot b) + 2 \cdot \exp\left[-2 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right] \cdot \exp(-\pi \cdot f \cdot b) \cdot \cos(\pi \cdot f \cdot b) - \exp\left[-2 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] - \exp\left[-2 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right]\right]$$

$$\frac{1}{2} \cdot a^{\left(\frac{1}{2}\right)} \cdot \pi^{\left(\frac{1}{4}\right)} \cdot \sqrt{2} \cdot \left[\left[\exp\left[-2 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] \cdot \exp(2 \cdot i \cdot \pi \cdot f \cdot b) + \exp\left[-2 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right] \cdot (\exp(-2 \cdot i \cdot \pi \cdot f \cdot b))\right]\right]$$

modulus

$$\left|\frac{1}{2} \cdot a^{\left(\frac{1}{2}\right)} \cdot \pi^{\left(\frac{1}{4}\right)} \cdot \sqrt{2} \cdot \left[\left[\exp\left[-2 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] \cdot \exp(2 \cdot i \cdot \pi \cdot f \cdot b) + \exp\left[-2 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right] \cdot (\exp(-2 \cdot i \cdot \pi \cdot f \cdot b))\right]\right]\right|$$

$$\frac{1}{2} \cdot \pi^{\left(\frac{1}{4}\right)} \cdot \left[\left[\exp\left[-4 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] - 2 \cdot \exp\left[-4 \cdot \pi^2 \cdot \left(f^2 \cdot a^2 + f0^2\right)\right] + \exp\left[-4 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right] + 4 \cdot \cos(2 \cdot \pi \cdot f \cdot b)^2 \cdot \exp\left[-4 \cdot \pi^2 \cdot \left(f^2 \cdot a^2 + f0^2\right)\right]\right] \cdot (2 \cdot a)\right]^{\left(\frac{1}{2}\right)}$$

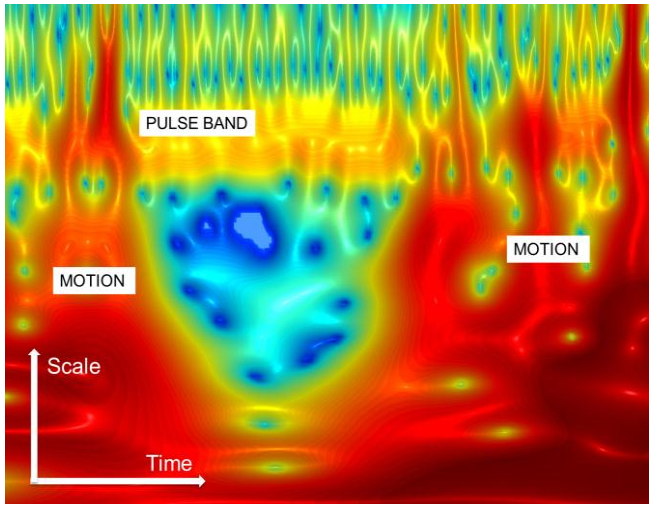
sine half

$$\int_{-\infty}^{\infty} \frac{a^{\left(\frac{1}{2}\right)}}{\pi^{\left(\frac{1}{4}\right)}} \cdot \exp(2 \cdot i \cdot \pi \cdot f0 \cdot t) \cdot \exp\left(\frac{-1}{2} \cdot t^2\right) \cdot i \cdot \sin(2 \cdot \pi \cdot f \cdot (a \cdot t + b))\, dt$$

$$-i \cdot \frac{a^{\left(\frac{1}{2}\right)}}{\pi^{\left(\frac{1}{4}\right)}} \cdot \int_{-\infty}^{\infty} 4 \cdot \exp(i \cdot \pi \cdot f0 \cdot t)^2 \cdot \exp\left(\frac{-1}{2} \cdot t^2\right) \cdot \sin(\pi \cdot f \cdot t \cdot a) \cdot \cos(\pi \cdot f \cdot t \cdot a) \cdot \cos(\pi \cdot f \cdot b)^2 - 2 \cdot \exp(i \cdot \pi \cdot f0 \cdot t)^2 \cdot \exp\left(\frac{-1}{2} \cdot t^2\right) \cdot \sin(\pi \cdot f \cdot t \cdot a) \cdot \cos(\pi \cdot f \cdot t \cdot a) + 4 \cdot \exp(i \cdot \pi \cdot f0 \cdot t)^2 \cdot \exp\left(\frac{-1}{2} \cdot t^2\right) \cdot \cos(\pi \cdot f \cdot t \cdot a)^2 \cdot \sin(\pi \cdot f \cdot b) \cdot \cos(\pi \cdot f \cdot b) - 2 \cdot \exp(i \cdot \pi \cdot f0 \cdot t)^2 \cdot \exp\left(\frac{-1}{2} \cdot t^2\right) \cdot \sin(\pi \cdot f \cdot b) \cdot \cos(\pi \cdot f \cdot b)\, dt$$

$$\frac{-i}{2} \cdot i \cdot a^{\left(\frac{1}{2}\right)} \cdot \pi^{\left(\frac{1}{4}\right)} \cdot \sqrt{2} \cdot \left[-2 \cdot i \cdot \exp\left[-2 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] \cdot \cos(\pi \cdot f \cdot b)^2 + 2 \cdot i \cdot \exp\left[-2 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right] \cdot \cos(\pi \cdot f \cdot b)^2 + i \cdot \exp\left[-2 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] - i \cdot \exp\left[-2 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right] + 2 \cdot \exp\left[-2 \cdot \pi^2 \cdot (f \cdot a + f0)^2\right] \cdot \cos(\pi \cdot f \cdot b) \cdot \sin(\pi \cdot f \cdot b) + 2 \cdot \exp\left[-2 \cdot \pi^2 \cdot (-f0 + f \cdot a)^2\right] \cdot \cos(\pi \cdot f \cdot b) \cdot \sin(\pi \cdot f \cdot b)\right]$$

V



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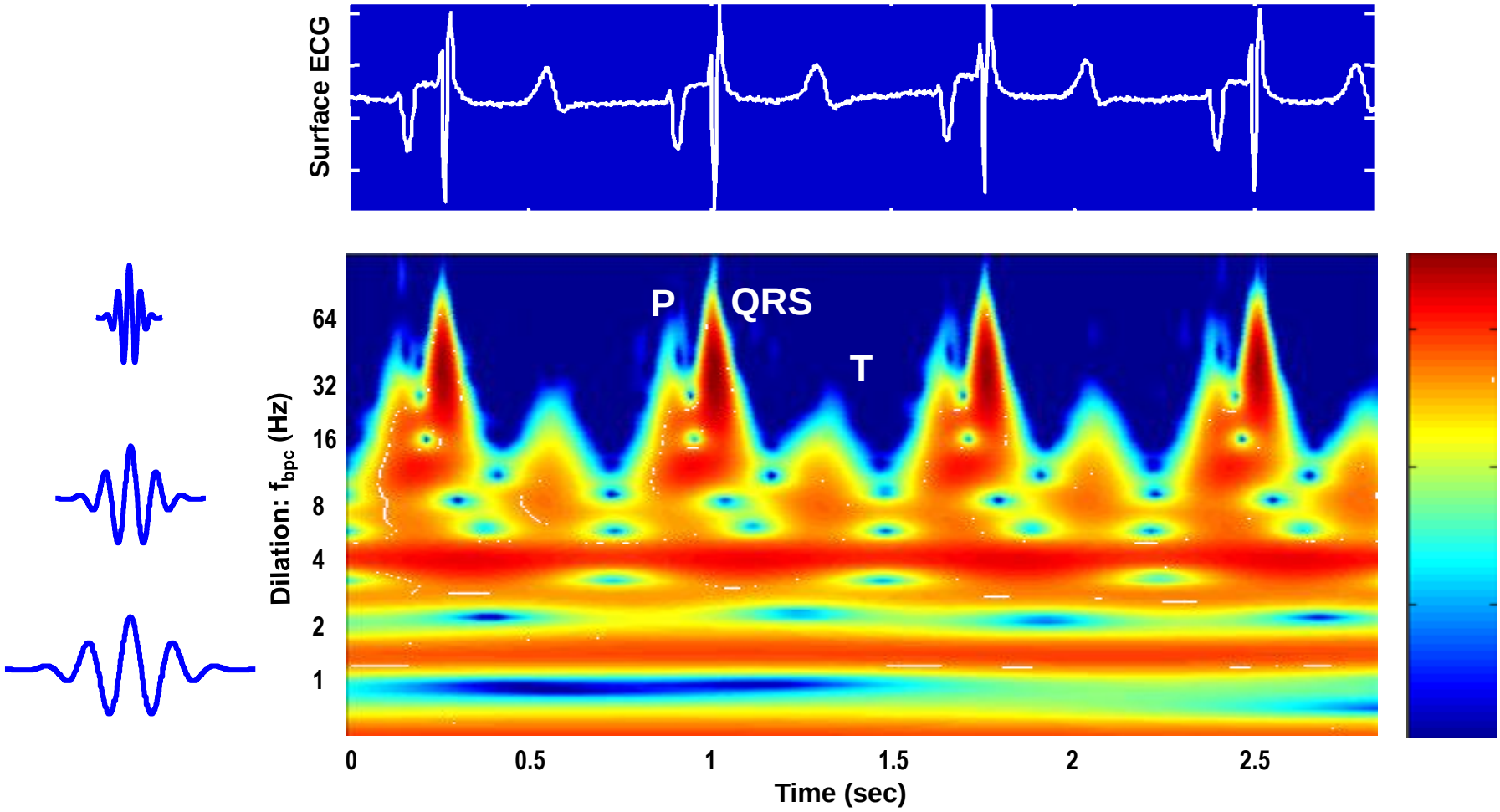
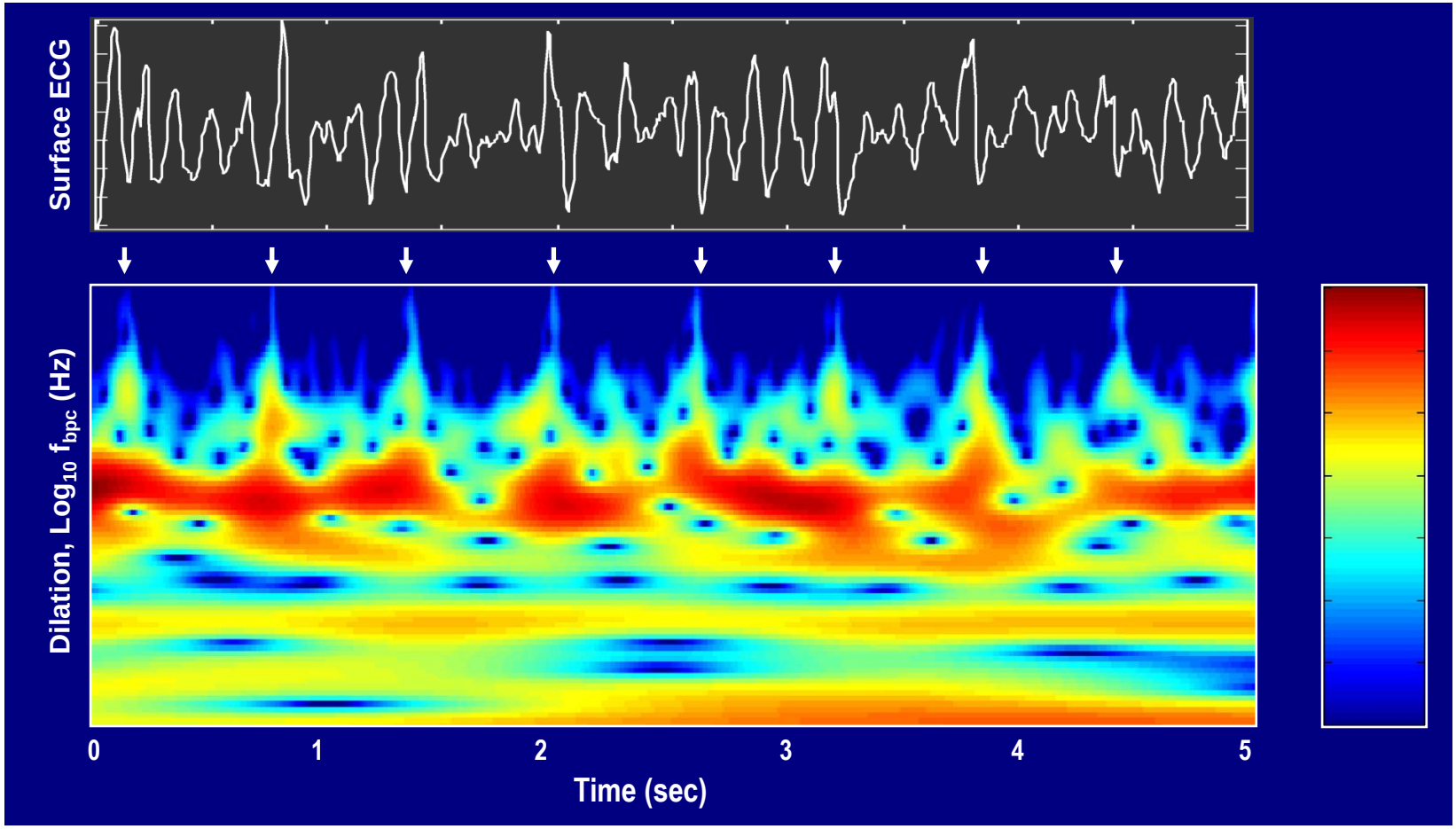
ECG – Sinus Rhythm



Scalogram for 3 seconds of sinus rhythm

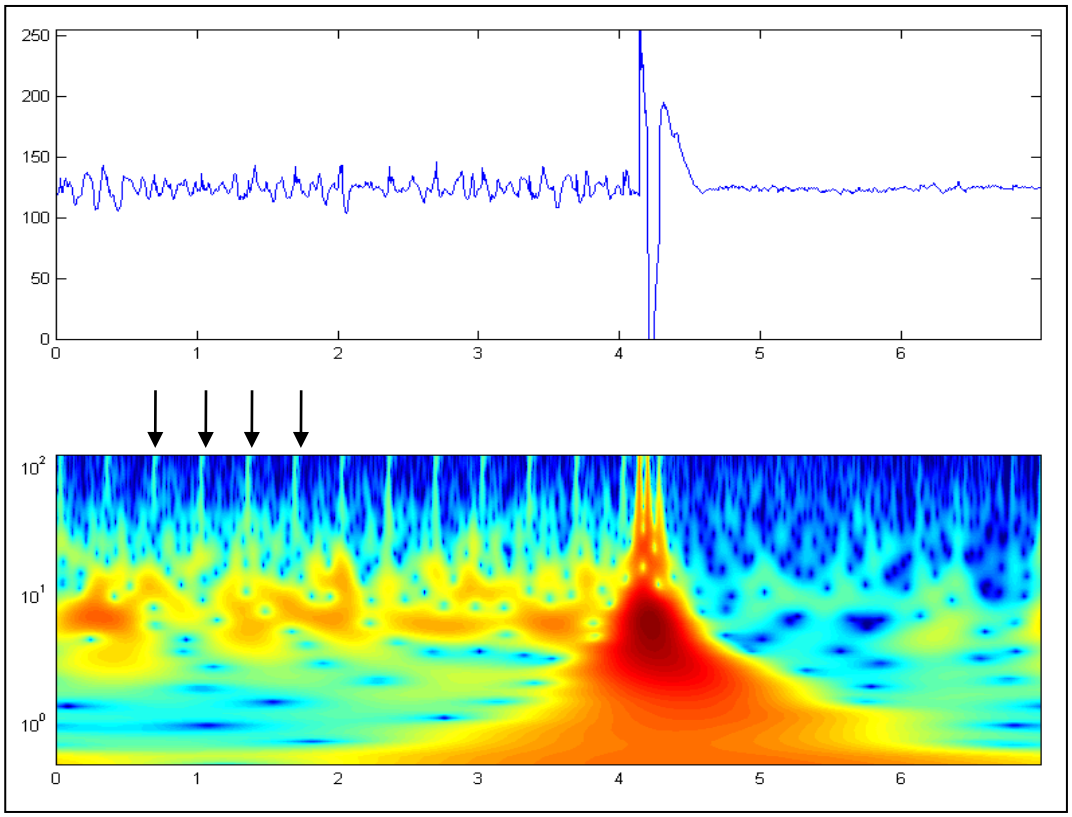
ECG – Segment of Porcine VF



Regular background spiking in signal

log amplitude plot picks up detail orders of magnitude less than dominant VF signal !!!

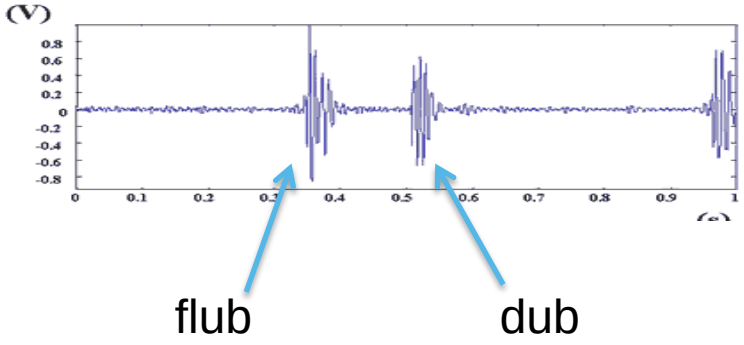
ECG – Human VF



- **Again subtle background (regular) information in VF**
- **Information is quantified and used in classifier for shock outcome prediction**

Phonocardiogram

A Clean PCG



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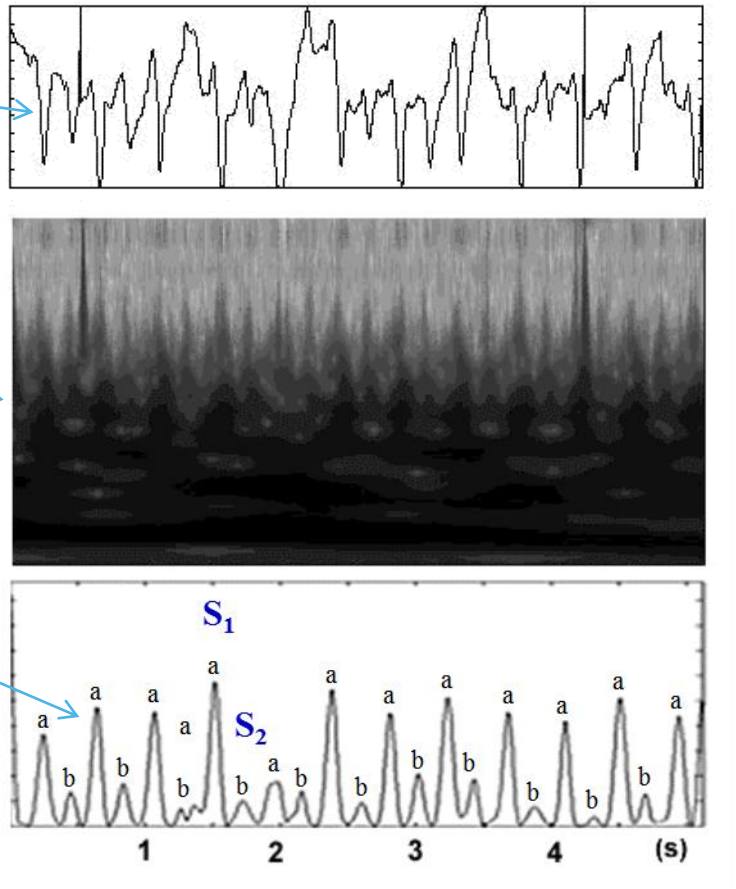
Neonatal Phonocardiogram

- SMART clothing PCG signals which exhibit excessive noise, movement artefact and under-sampling. (cf clean signal above)
- Wavelet transform of signal
- Extracting an envelope of S1 and S2 sounds from wavelet surface – this provides a method for monitoring heart rate.



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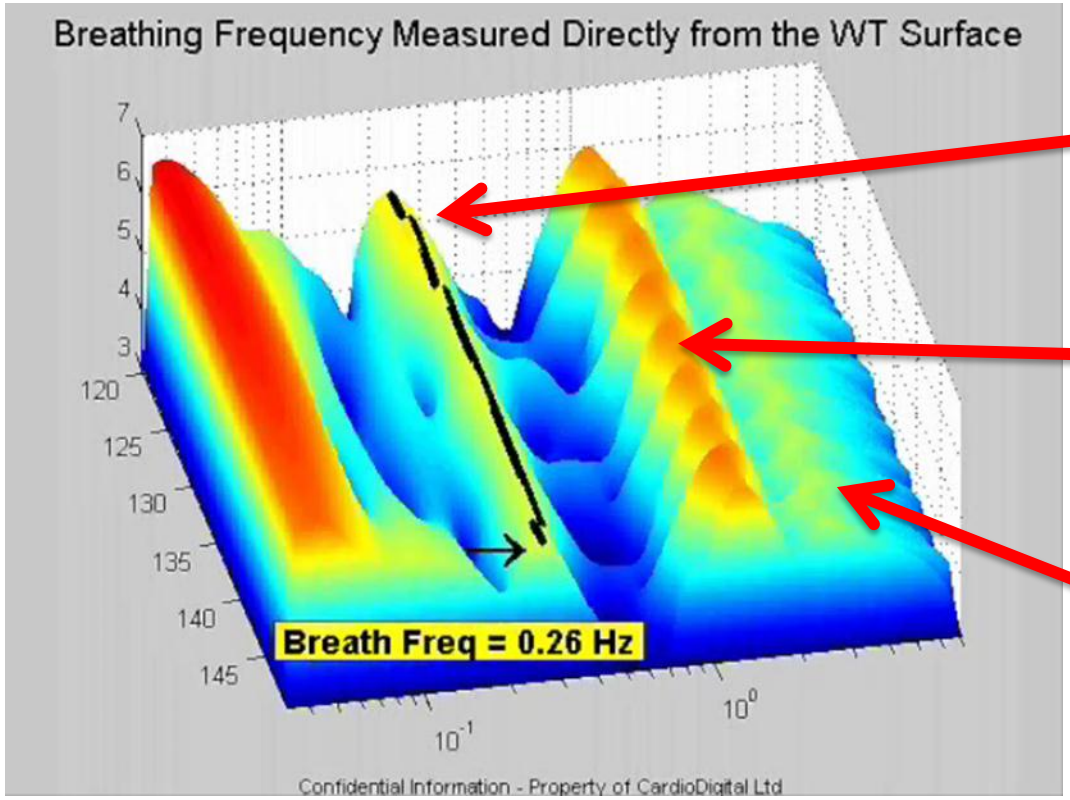
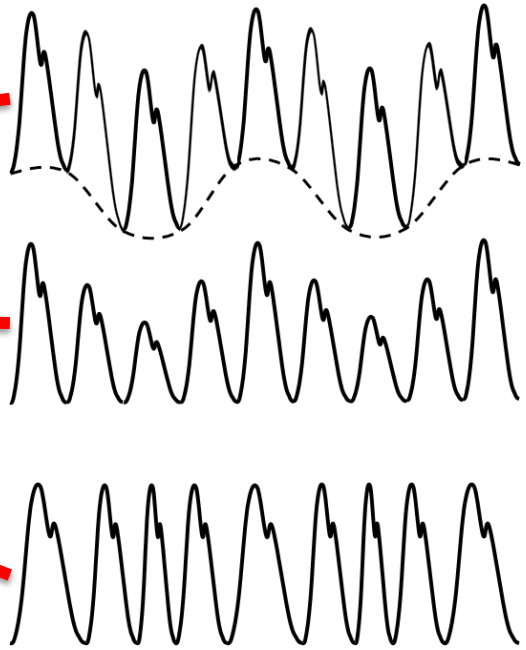
Photoplethysmogram

Numerous modulations due to respiration – all obvious in the transform





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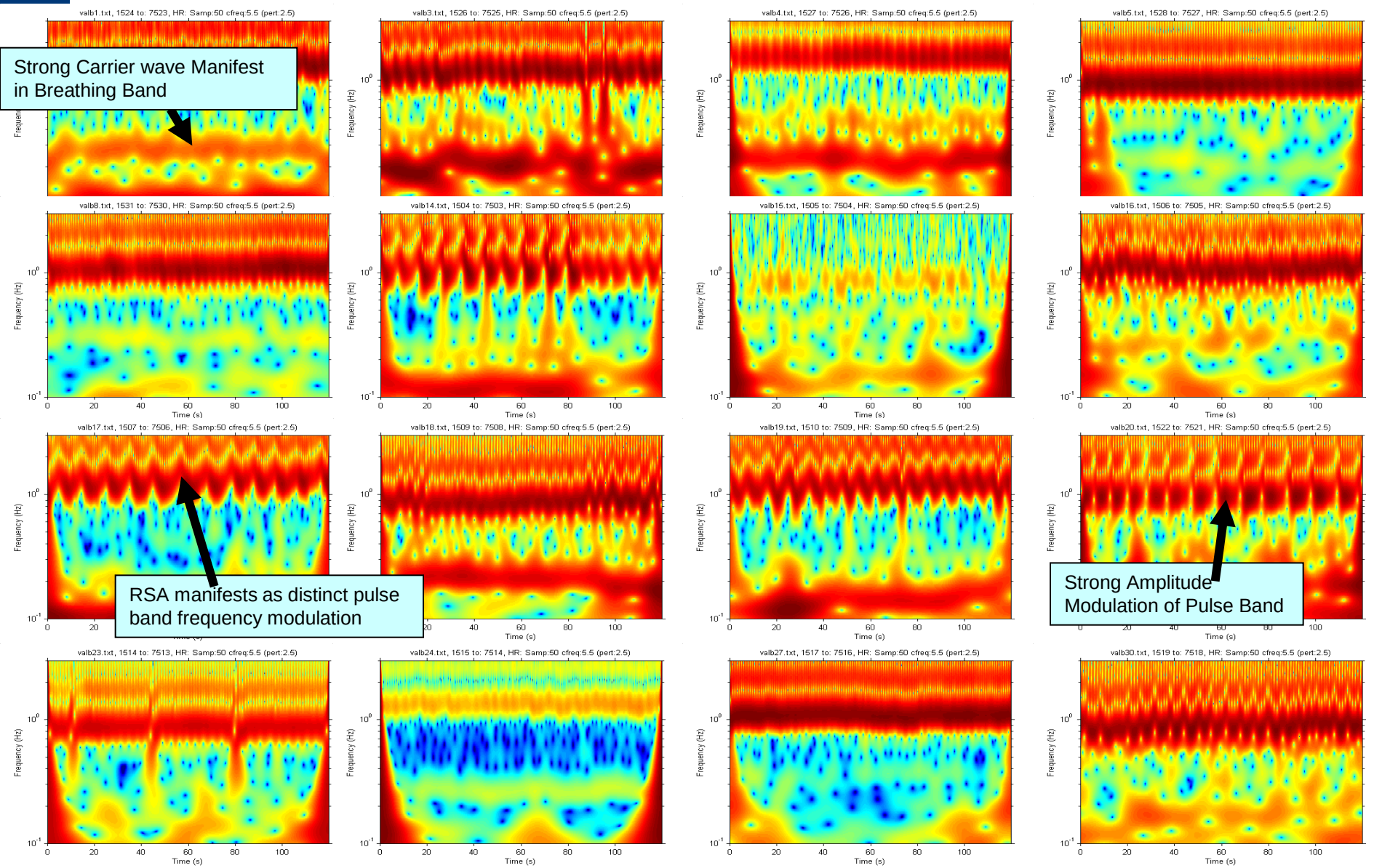
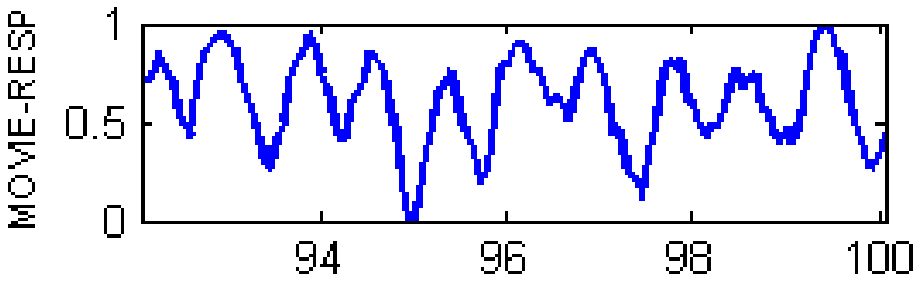
Inter-Subject Variability of Components

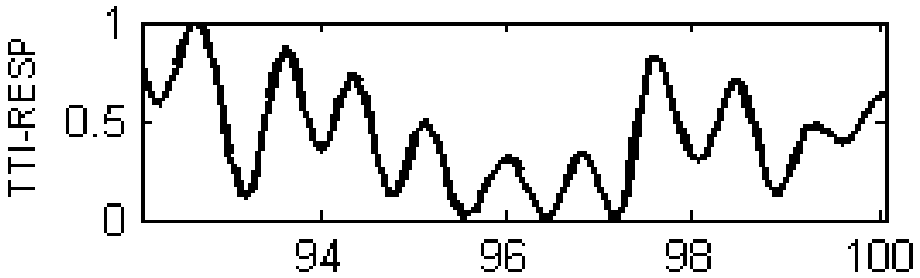
These scalograms are computed from 16 healthy patients.

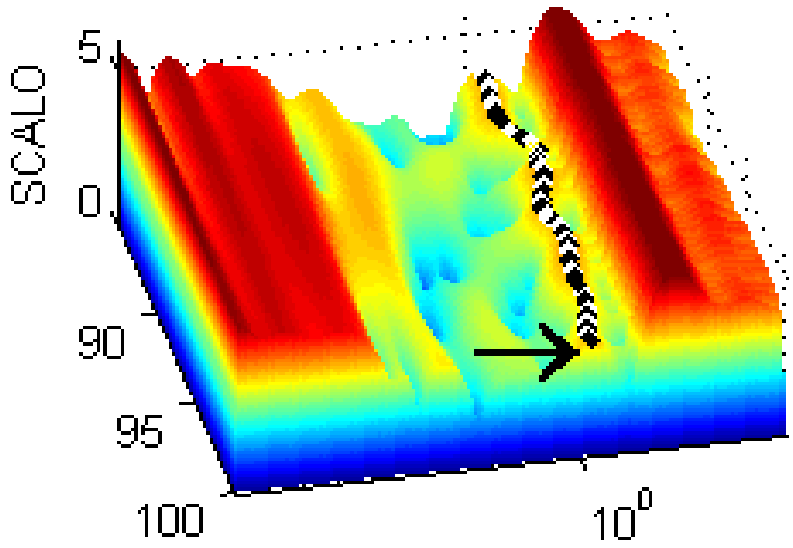


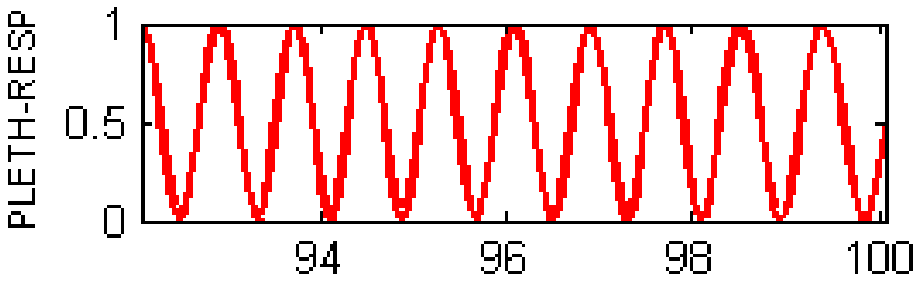
Neonatal Monitoring

Respiration Monitoring from the Pulse Oximeter 'Pleth' Waveform









PlethRESP™ TECHNOLOGY

Summary

- Developing a clinically useful physiological device parameter is a distinctly non-trivial task.
- Algorithms require a number of sophisticated pre-processing and post-processing code modules, alarm management systems, hardware interface routines, and often involve thousands of lines of computer code.
- Wouldn’t it be great if we could see what we are aiming for?

Summary

- The genesis of a new parameter should involve a “softer” side of signal processing where the tools involved need to inform at the conceptual level. - *Look before you leap!*
- “Upstream” use of the Wavelet Transform - a soft tool to aid comprehension through rapid visualization of underlying signal components.
- Provides insight into the feasibility of the underlying task
- Facilitates the development of signal processing strategies for attacking the problem to be solved.

A picture is worth a thousand words!

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A picture is worth a thousand ~~words~~!

– lines of wasted computer code!

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end

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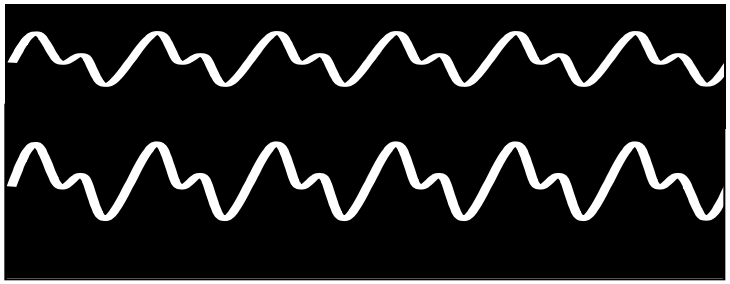
NOVOSAT™

Complementary Technology
- new method of SpO2 measurement

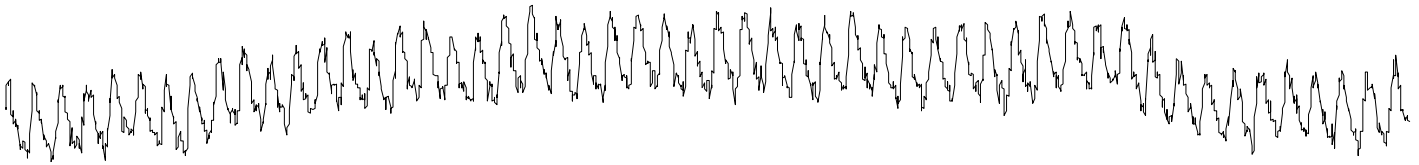


Red Signal

Infrared Signal

Ratio of R/IR → **Look up table** → **Ox Sats $Sp0_2$**

BUT



Real signal suffers from hf noise, drift & movement

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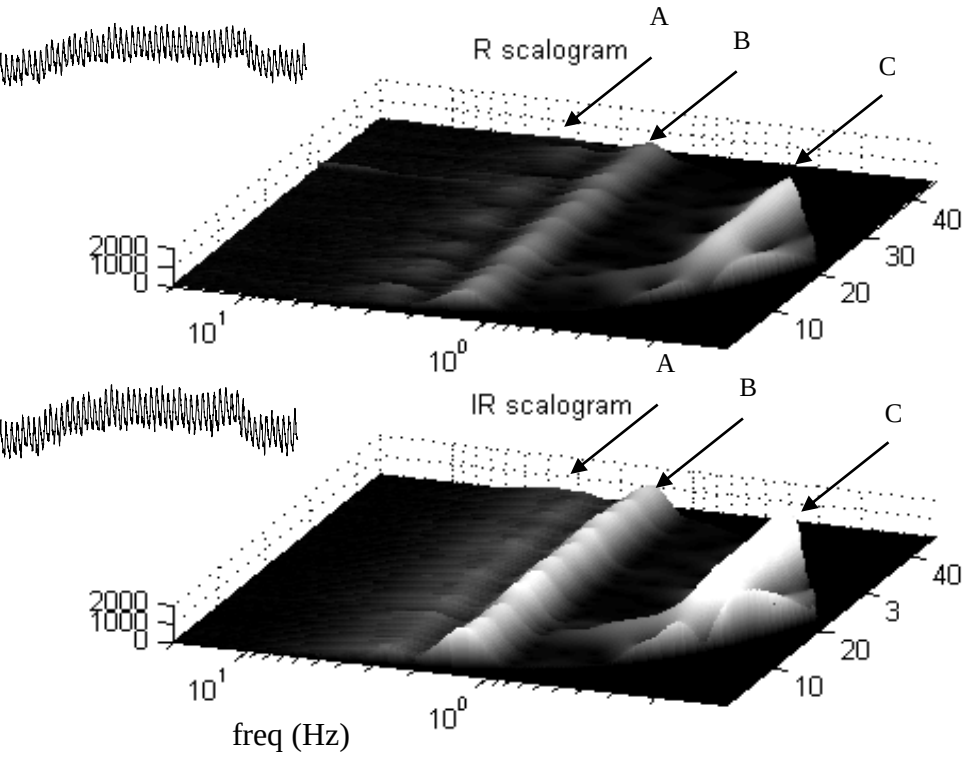
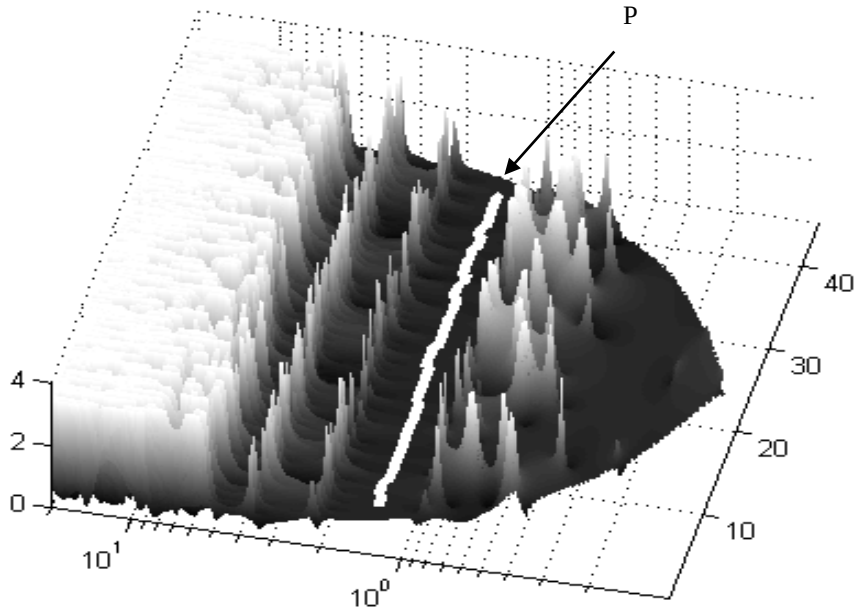
NovoSAT - RatioSurface

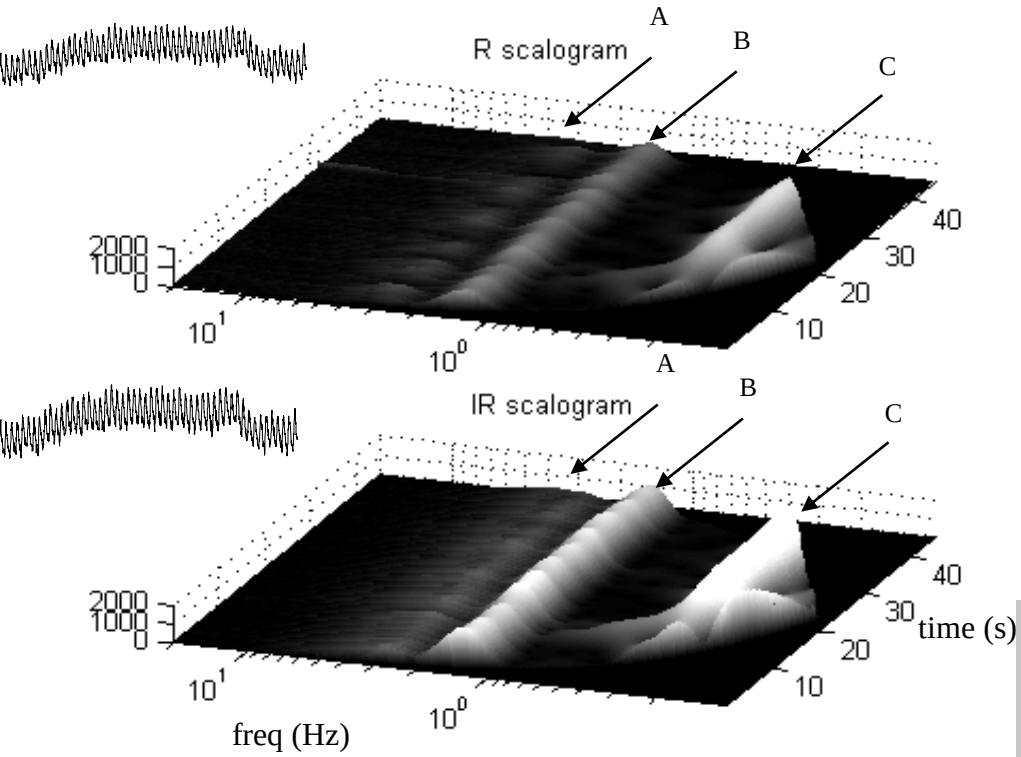


Ratio of R/IR | CWT Moduli

Wavelet Ratio Surface

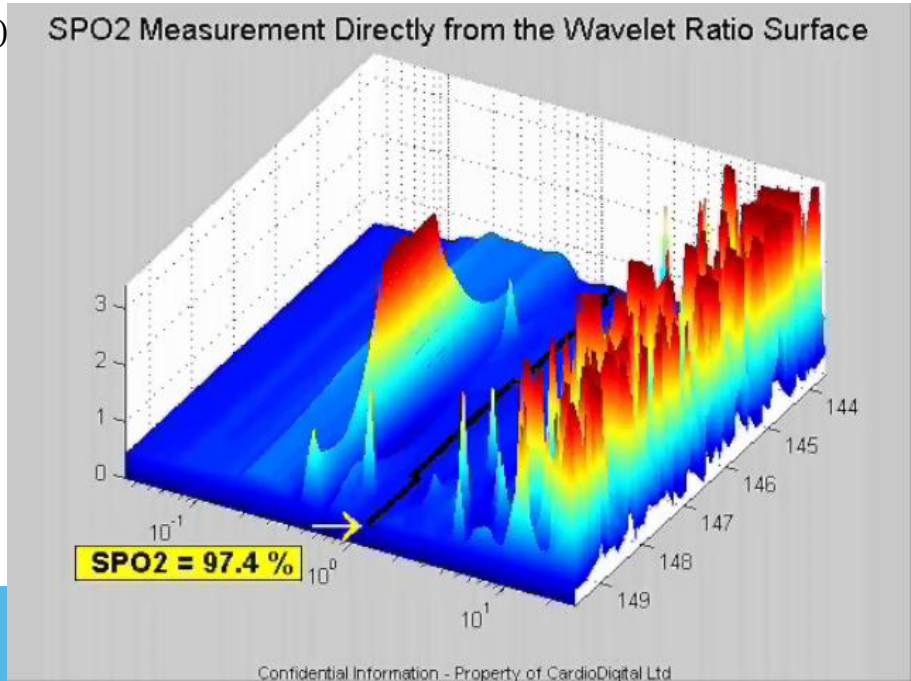


NovoSAT - RatioSurface

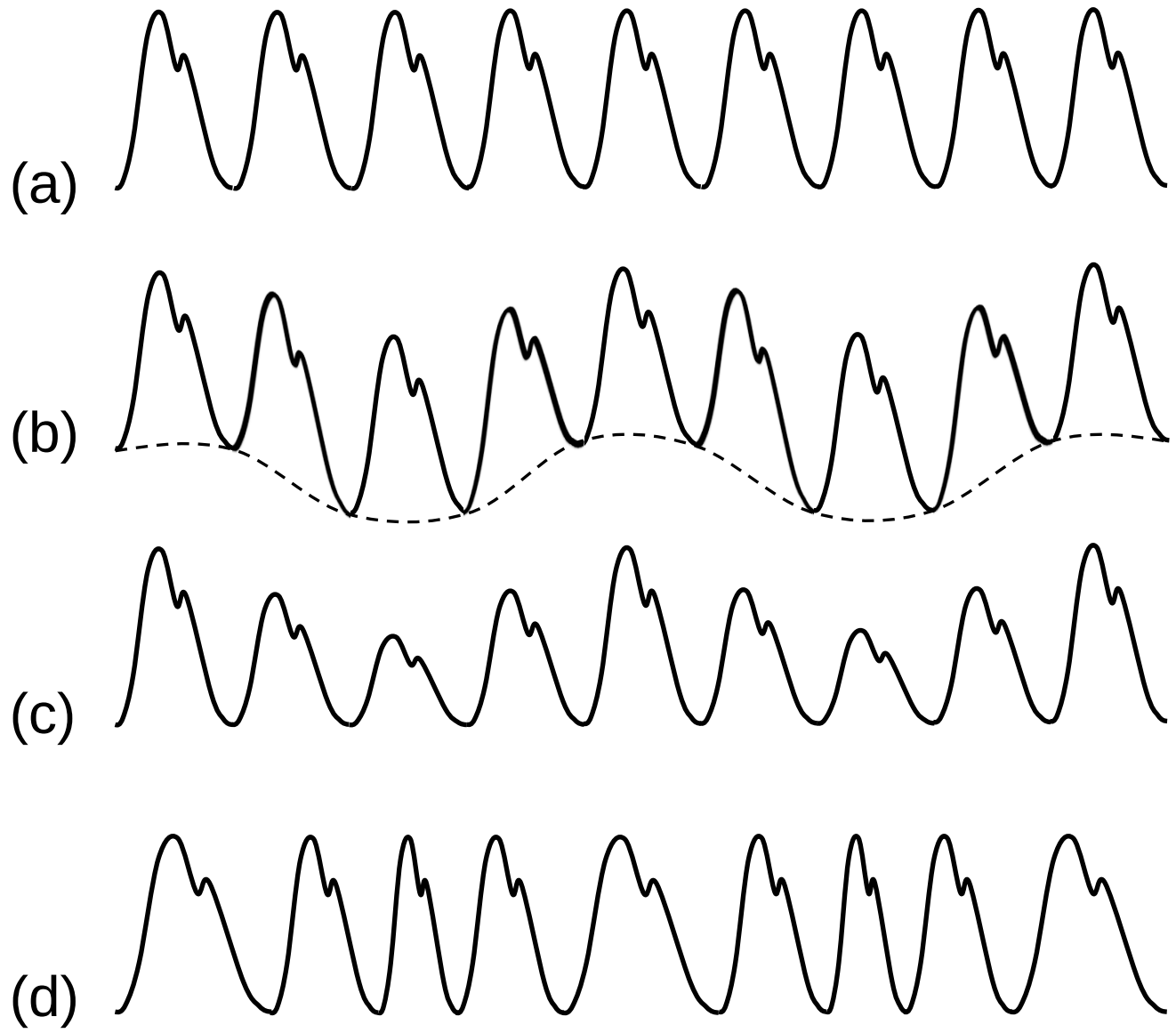


Ratio of R/IR | CWT Moduli

Wavelet Ratio Surface



WHAT WE MEASURE



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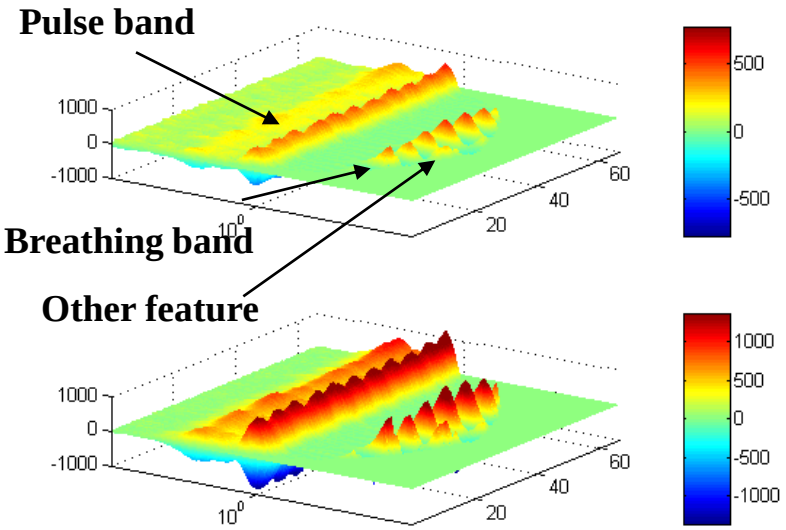
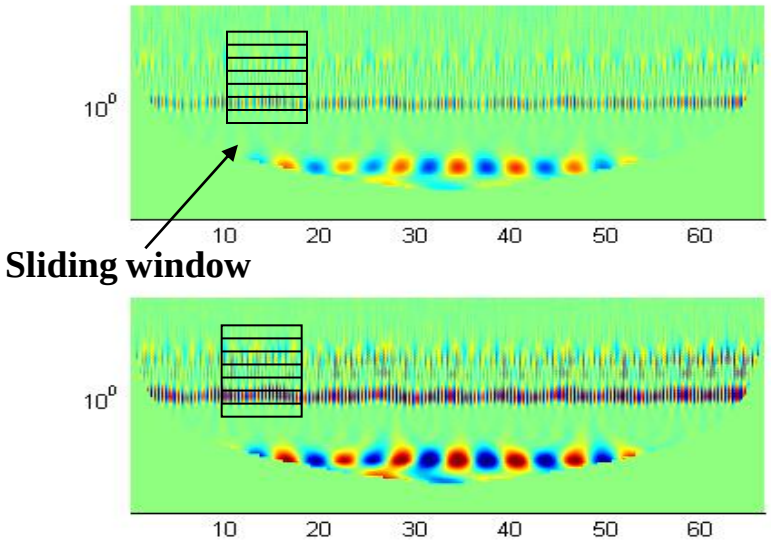
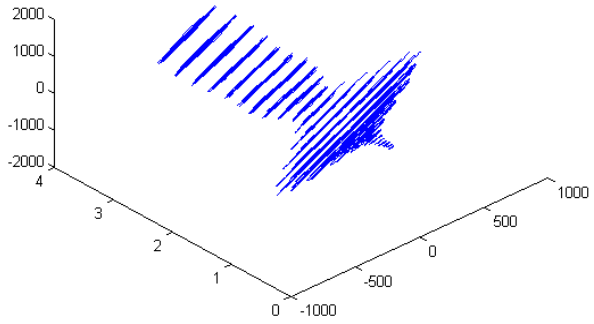
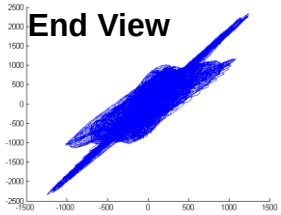
Pleth NovoSAT

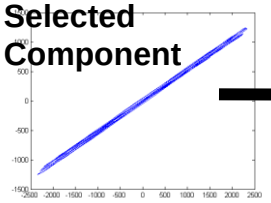
Lissajous





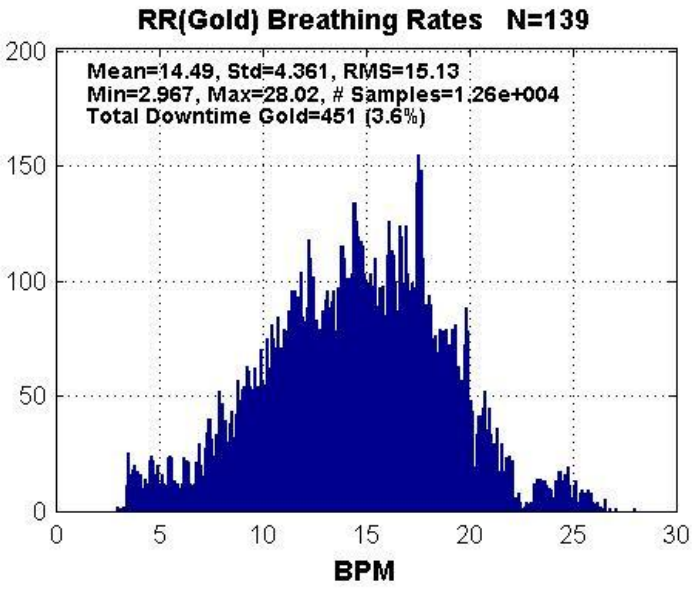


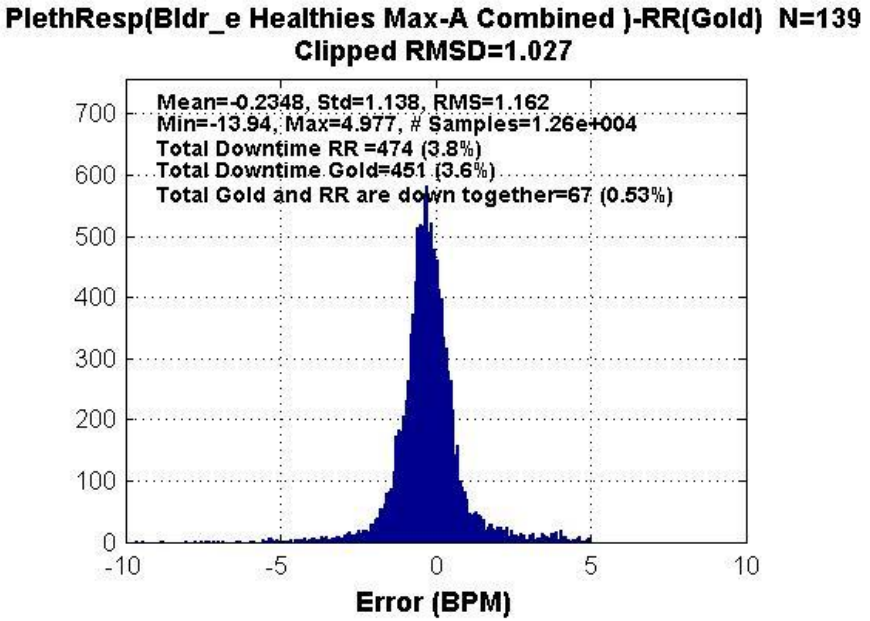


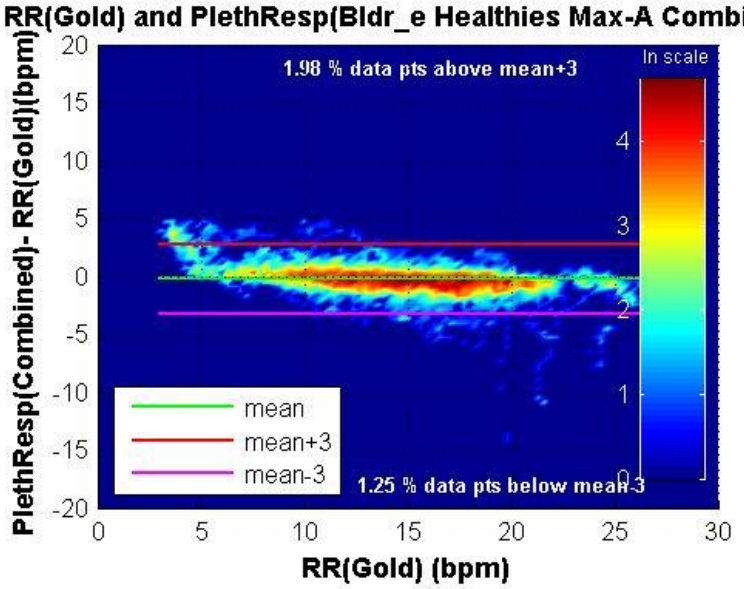


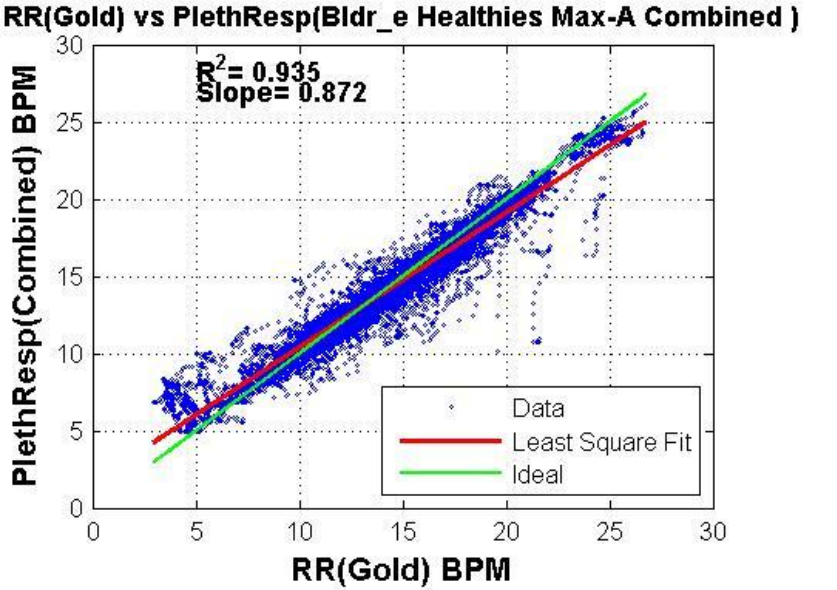
Slope - R/IR

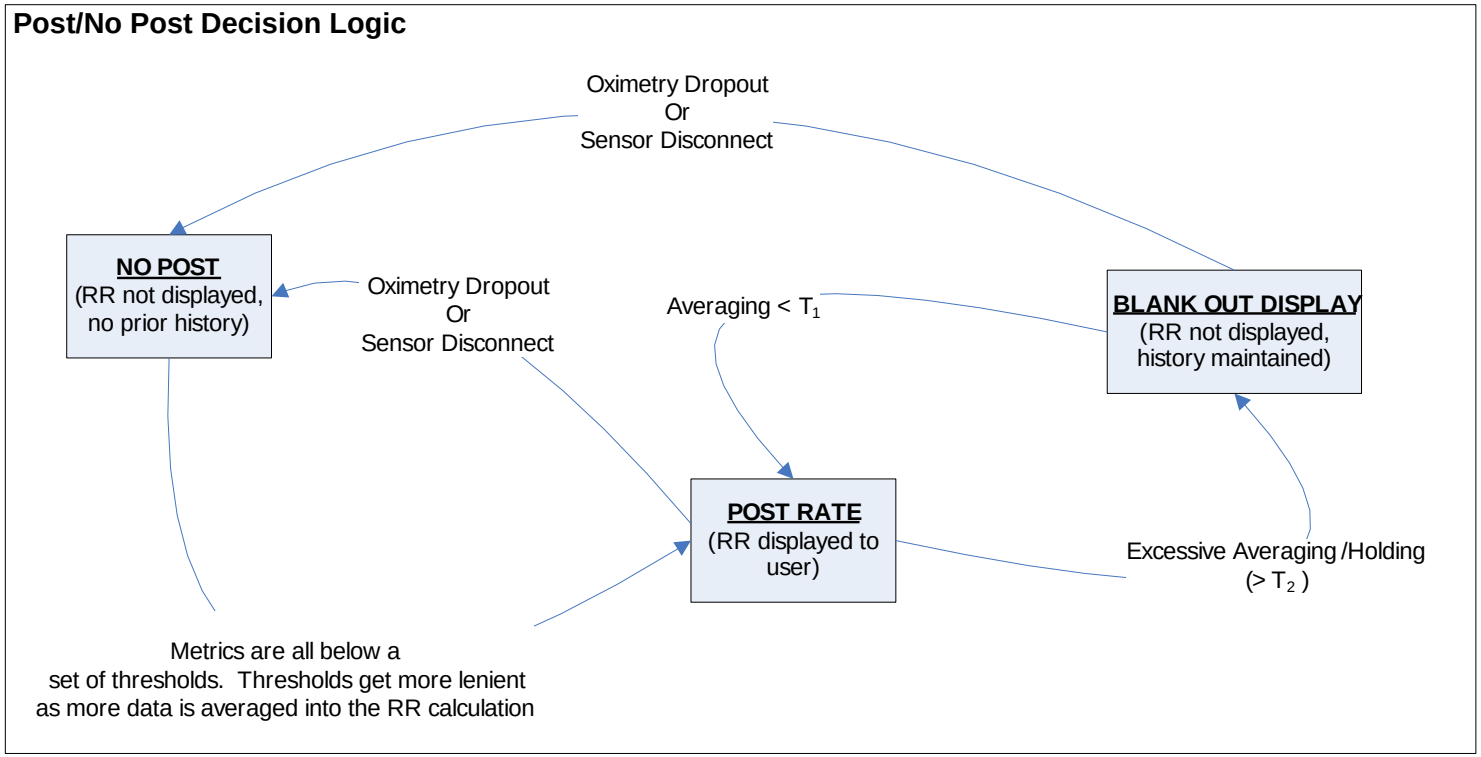
COVIDIEN


RR(Gold) Breathing Rates N=139
Mean=14.49, Std=4.361, RMS=15.13
Min=2.967, Max=28.02, # Samples=1.26e+004
Total Downtime Gold=451 (3.6%)
BPM


PlethResp(Bldr_e Healthies Max-A Combined)-RR(Gold) N=139
Clipped RMSD=1.027
Mean=-0.2348, Std=1.138, RMS=1.162
Min=-13.94, Max=4.977, # Samples=1.26e+004
Total Downtime RR =474 (3.8%)
Total Downtime Gold=451 (3.6%)
Total Gold and RR are down together=67 (0.53%)
Error (BPM)


RR(Gold) and PlethResp(Bldr_e Healthies Max-A Combined)
1.98 % data pts above mean+3
In scale
mean
mean+3
mean-3
1.25 % data pts below mean-3
PlethResp(Combined)- RR(Gold)(bpm)
RR(Gold) (bpm)


RR(Gold) vs PlethResp(Bldr_e Healthies Max-A Combined)
R2= 0.935
Slope= 0.872
Data
Least Square Fit
Ideal
PlethResp(Combined) BPM
RR(Gold) BPM


Post/No Post Decision Logic
Oximetry Dropout
Or
Sensor Disconnect
NO POST
(RR not displayed,
no prior history)
Oximetry Dropout
Or
Sensor Disconnect
Averaging < T1
BLANK OUT DISPLAY
(RR not displayed,
history maintained)
POST RATE
(RR displayed to
user)
Excessive Averaging /Holding
(> T2)
Metrics are all below a
set of thresholds. Thresholds get more lenient
as more data is averaged into the RR calculation

COVIDIEN