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How can the fluctuations in the motion of kayak-paddlers be used to estimate performance?

Intro – kayaking performace analysis project

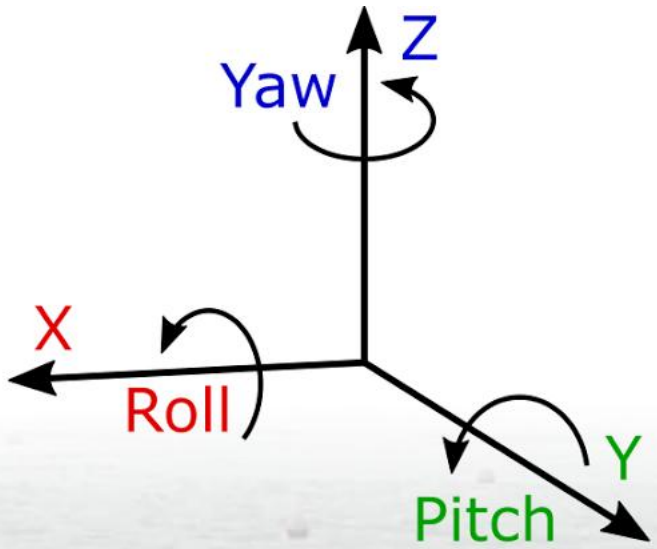
- Measurement and performance analysis of kayak paddling
  - Measurement – inertial sensors+data logging
  - Analysis: „traditonal”, more advanced?
- Signals: periodic+complex(not noise)+noise
- Noise: several sources
  - Sensor noise
  - Instrument noise
  - Noise in motion signals – information source?

Our approach

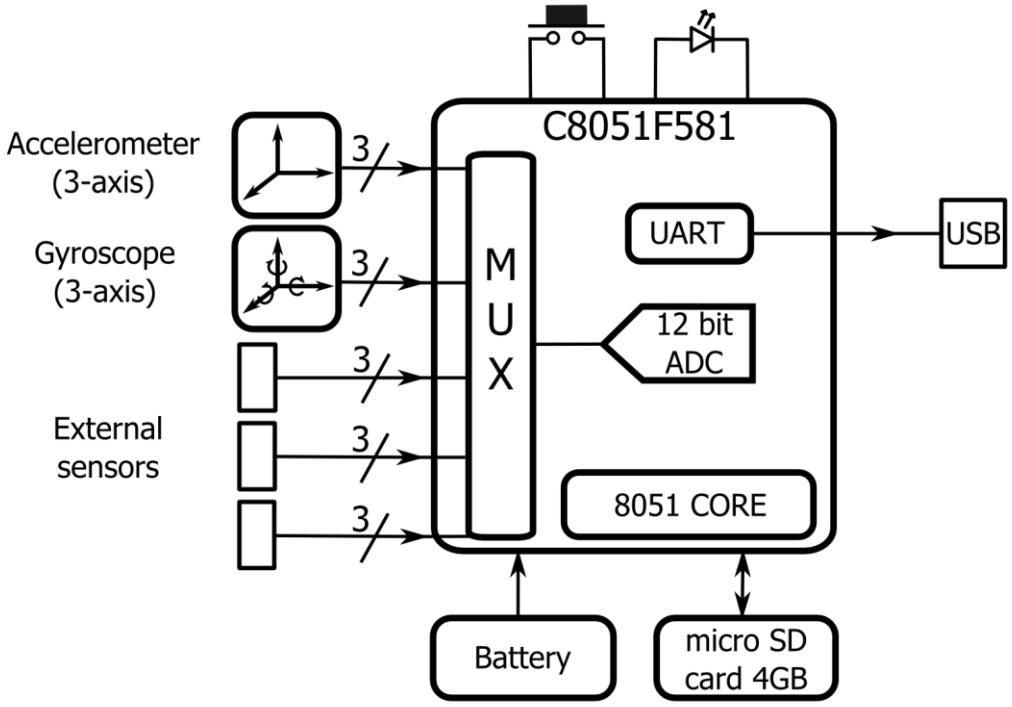
- periodic signals' shape and period have some fluctuations that can be informative.
- *From periodically working machines to heart beats the variability can be used to know more about proper behavior.*
- *Popular smart watches, wrist-bands, smart phones, actigraphs can detect motion patterns by inertial sensors – e.g. for monitoring of daily activity cycles for health analysis.*

Instrumentation basics

- Typical inertial sensors
  - Accelerometers (3 axis)
  - Gyroscopes (3 axis)
- Usual analysis



Our universal data acquisition device



- optimal dynamic range
- sample rate:
  1000 Hz per channel
- aliasing and noise reduction - passive filters
- further digital signal analysis

Further external sensors can be connected:

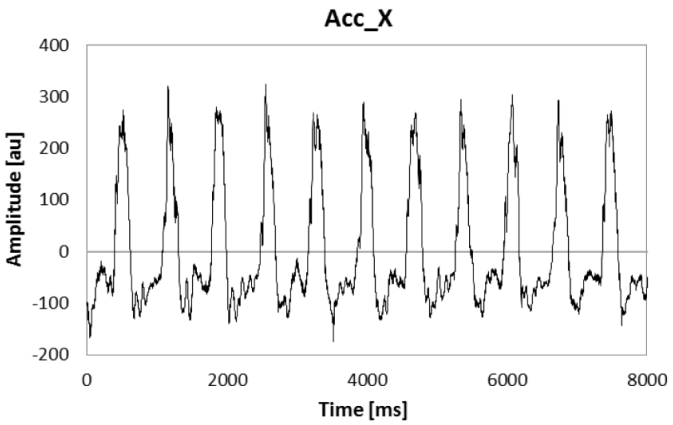
- physiological signals (e.g.: heart rate)
- forces in the paddle
- velocity
- more inertial signals…

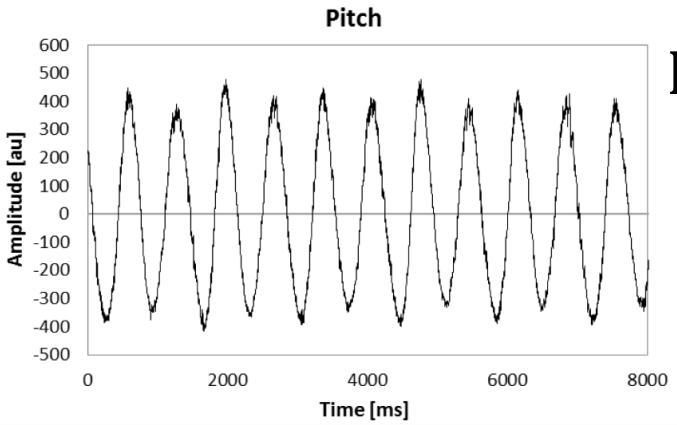
[1] G. Vadai et al. in 36th Int. Conv., Microelectronics, Electronics and Electronic Tech. 2013, pp. 144-149.

Acceleration

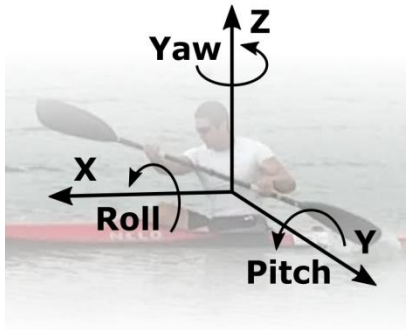
Angular velocity

X

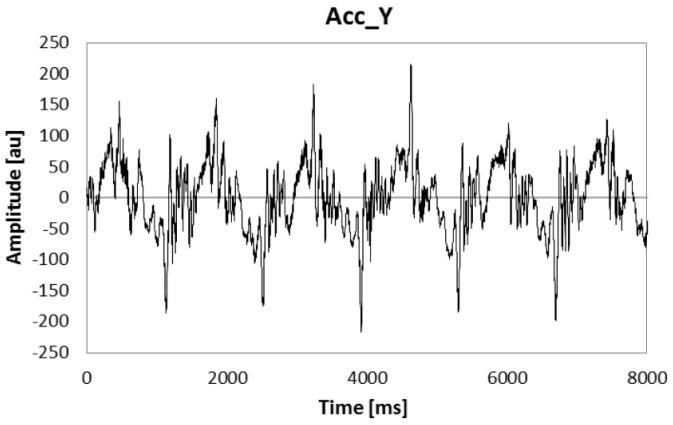


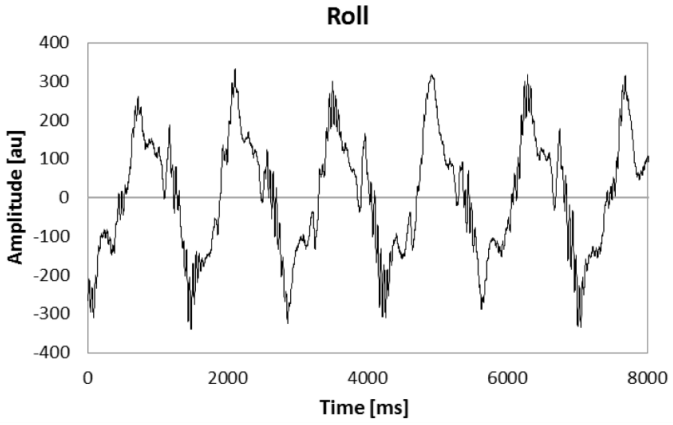


Pitch



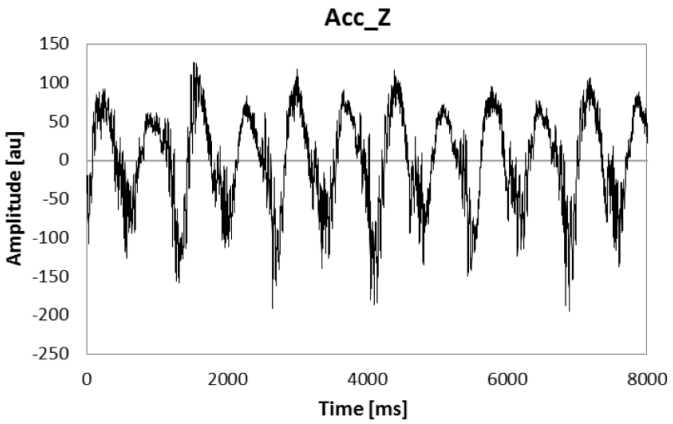
Y

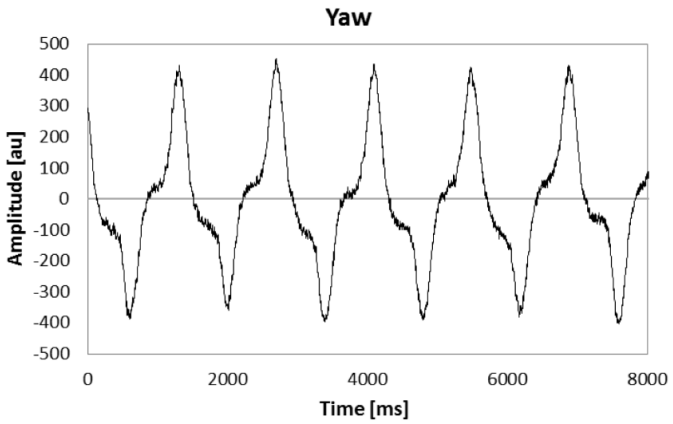




Roll

Z

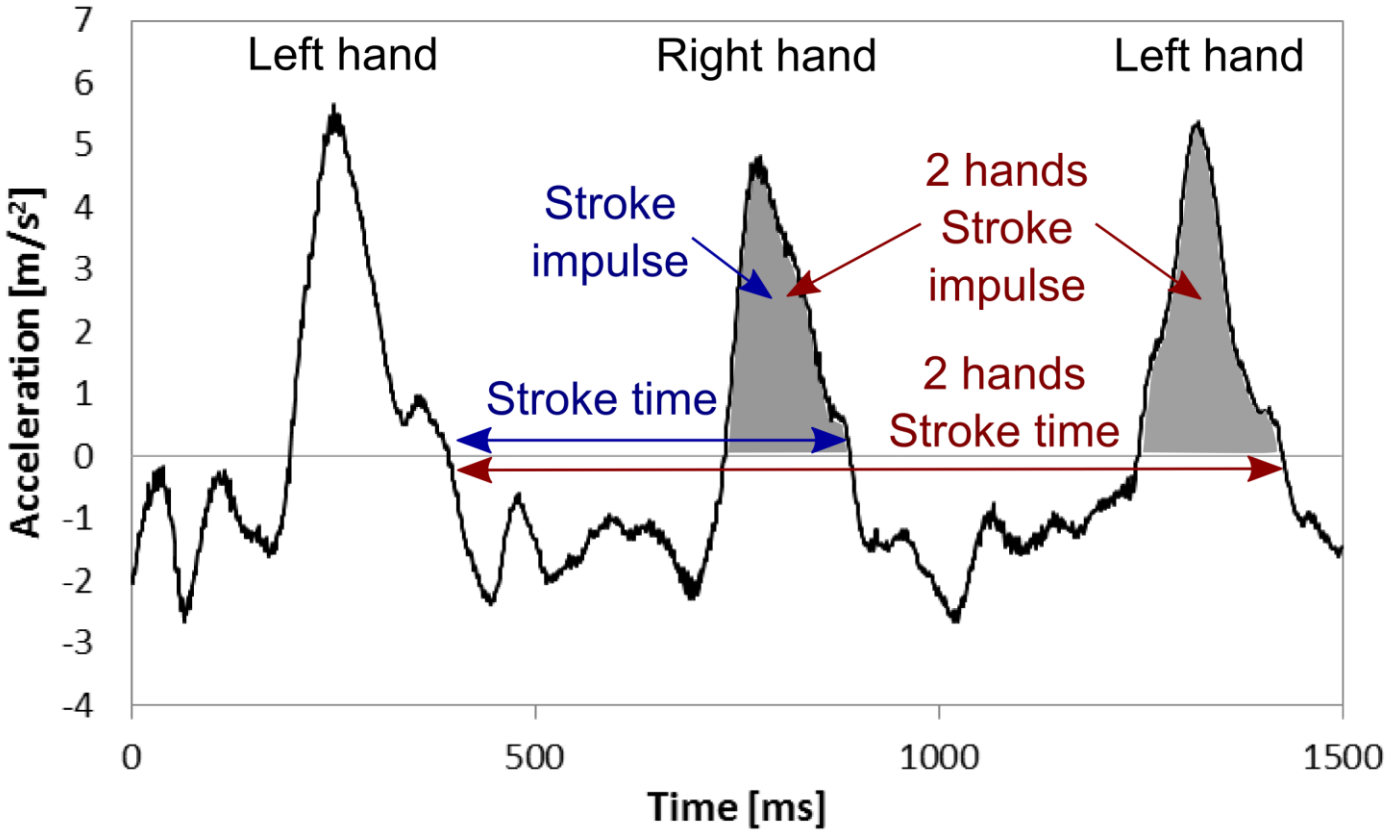




Yaw

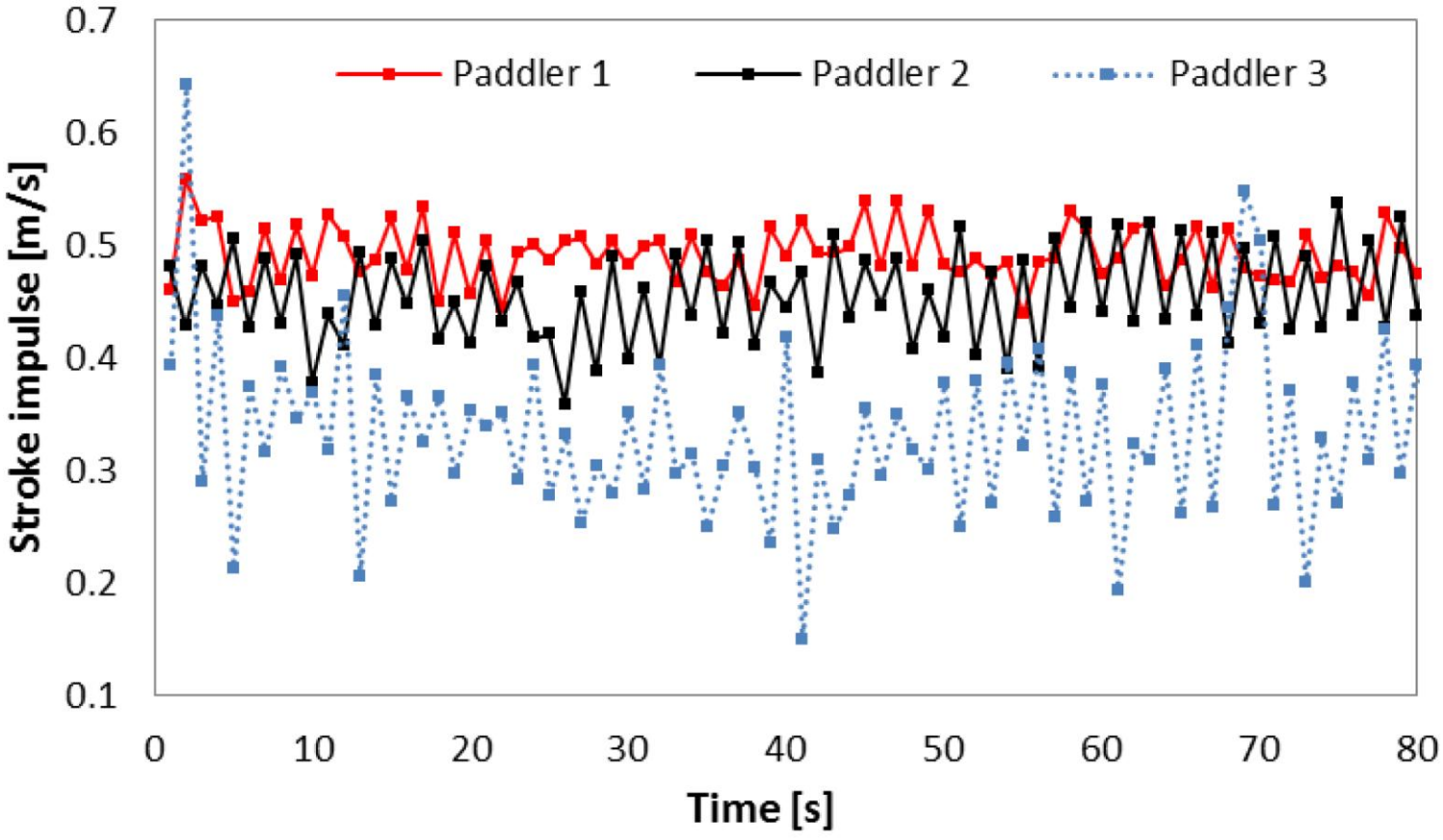
Periodic signal

- X-axis acceleration (forward axis)
- For stroke time only: gyroscope signal (yaw)



Stroke impulse trend – fluctuations?

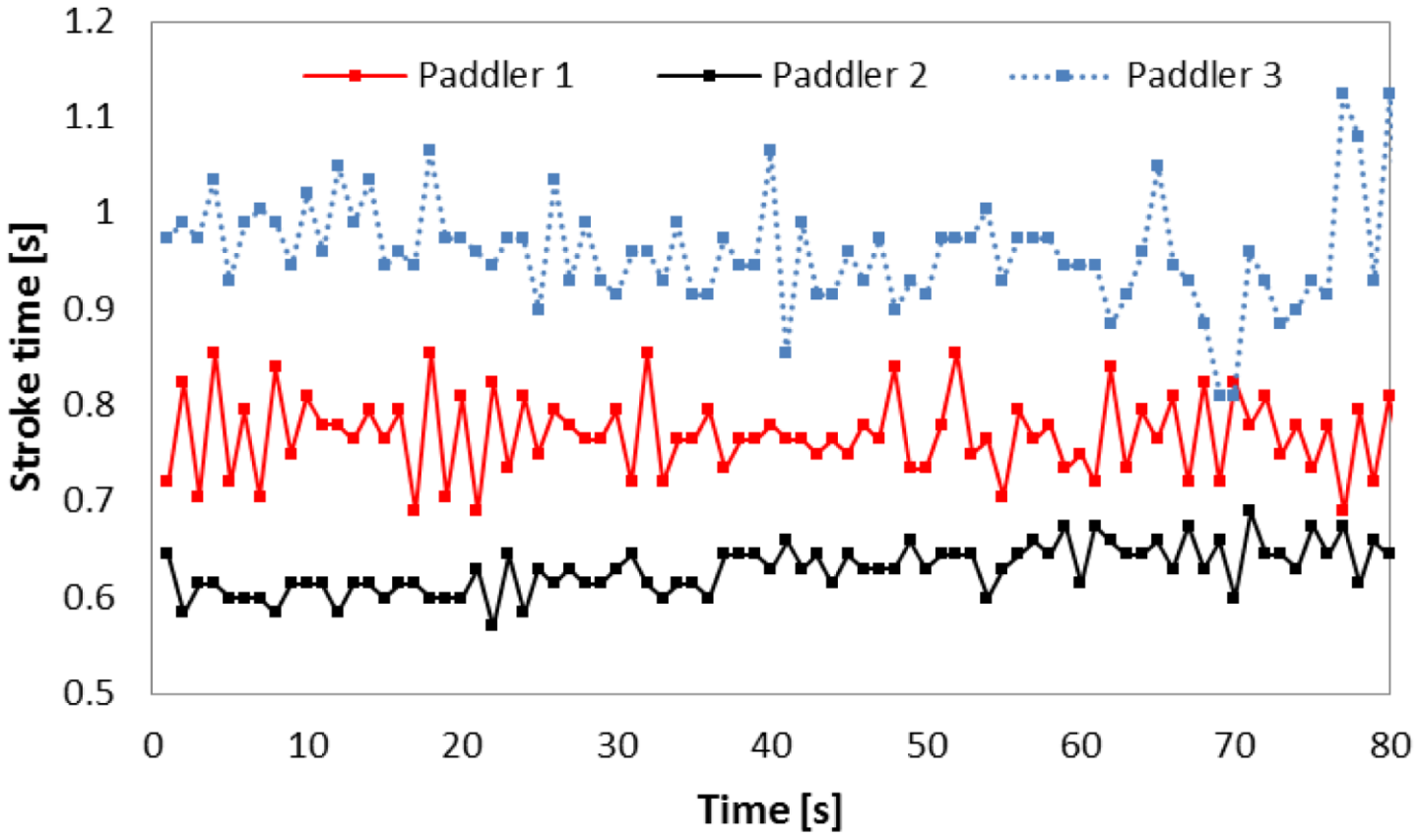
World Champion | **Professional (assymetric style)** | **Beginner (13 years old)**



[2] G. Vadai et al. In 22nd International Conference on Noise and Fluctuations, 2013, Paper 6579010.

Fluctuations of stroke times

World Champion | **Professional (assymetric style)** | **Beginner (13 years old)**



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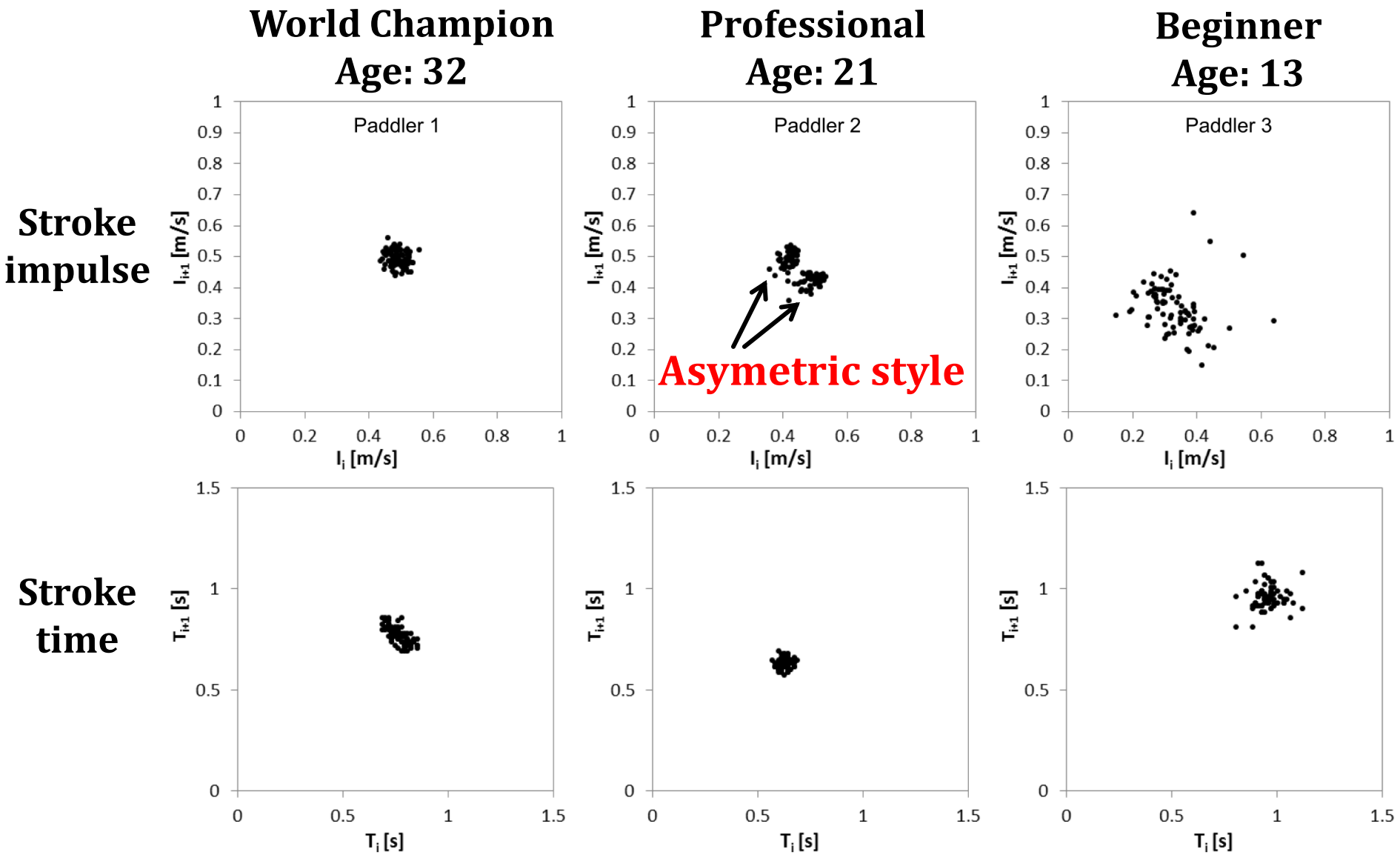
Poincaré maps



[2] G. Vadai et al. In 22nd Internationalé Conference on Noise and Fluctuations, 2013, Paper 6579010.

Performance analysis

- How can we classify performance/technical skills?
  - Athletes age
  - Classification by trainer
  - Race time…
- How we can compare paddlings?
  - Many different styles
  - Same paddler – different races, training tasks
  - Different paddlers
  - Various other conditions

Traditional indicators – problems

- Acceleration signal shape analysis
- Symmetry of left and right hand stroke
- Stroke impulse magnitude
- Stroke time
- Still several problems
  - Too complex raw data
  - Complicated analysis
  - Problems around relation to quality
  - E.g. stoke time is not closely related to performace

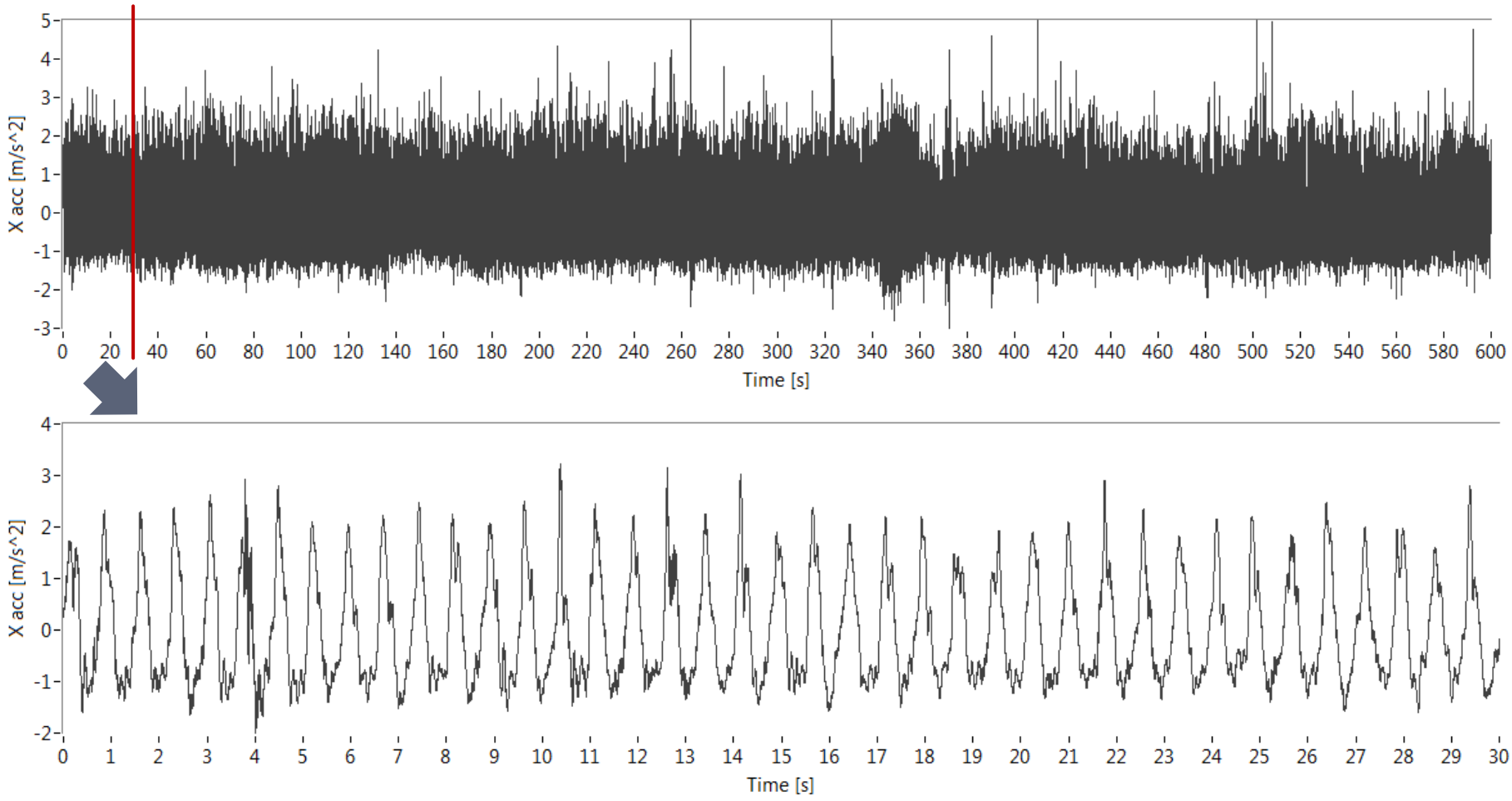
Motivation – use fluctuation analysis

- Simpler indicators? Numbers?
- Simpler, more reliable analysis?
- More reliable quality indicators?
  - Can fluctuation tell more than stroke impulse mean or trend?
  - Signal content, noise content, regular-irregular decomposition?
  - Signal-to-noise ratio?

Analyzed data

- Long range long training paddlings (>5 km)
  - First 10 minutes (2-3km)
- 14 athletes with different age and technical skills
- Plotted in the function of trainers' classification (score: 0-10, lowest to highest)
- Indicators were calculated for shorter window lengths (30 sec), and the averages for 10 minutes were compared

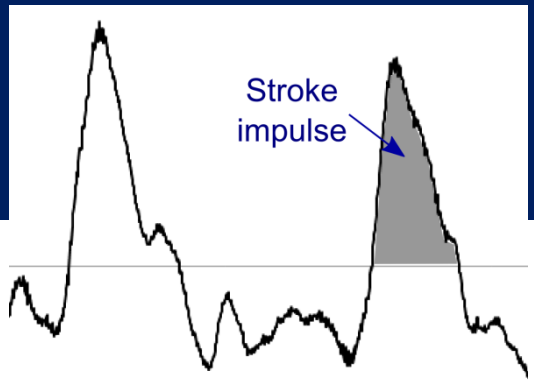
Temporal analysis – x axis acceleration



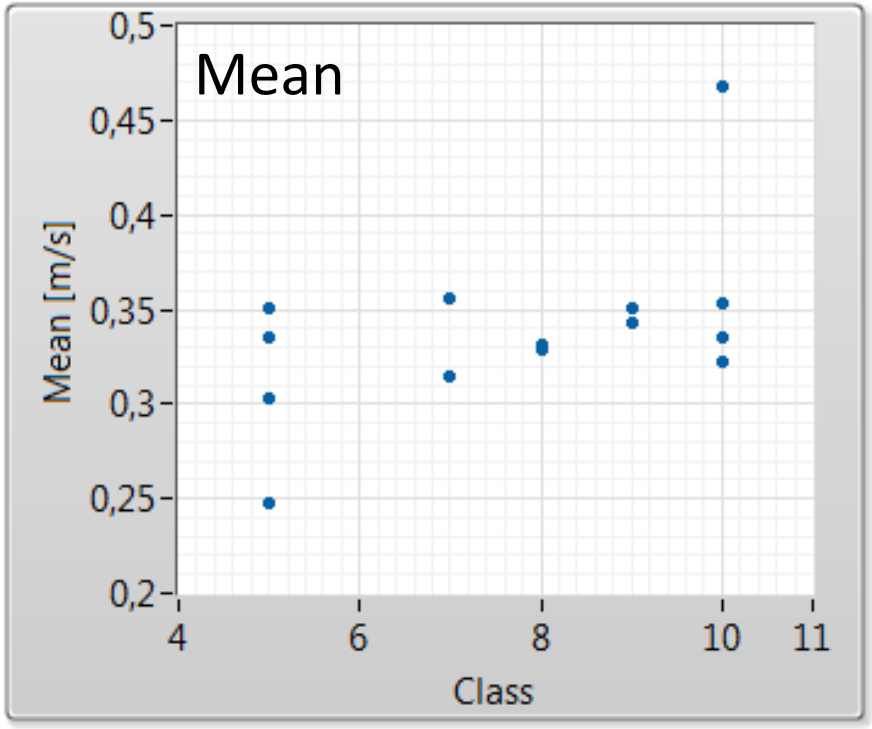
Peak detection → Stroke impulse Stroke time → Mean Standard dev. → Averaging for 10 min (20 windows)

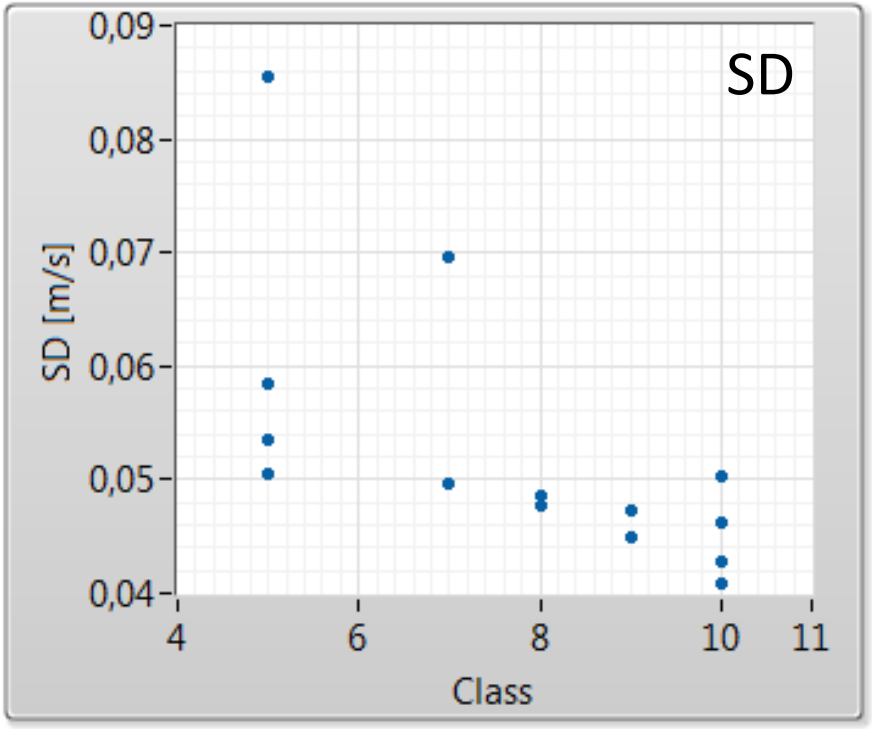
Proposed analysis and open problems

Temporal indicators

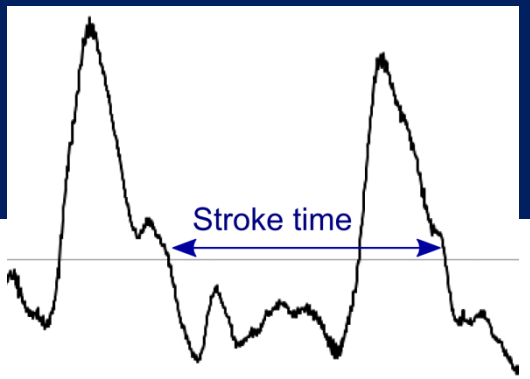


- Stroke impulse

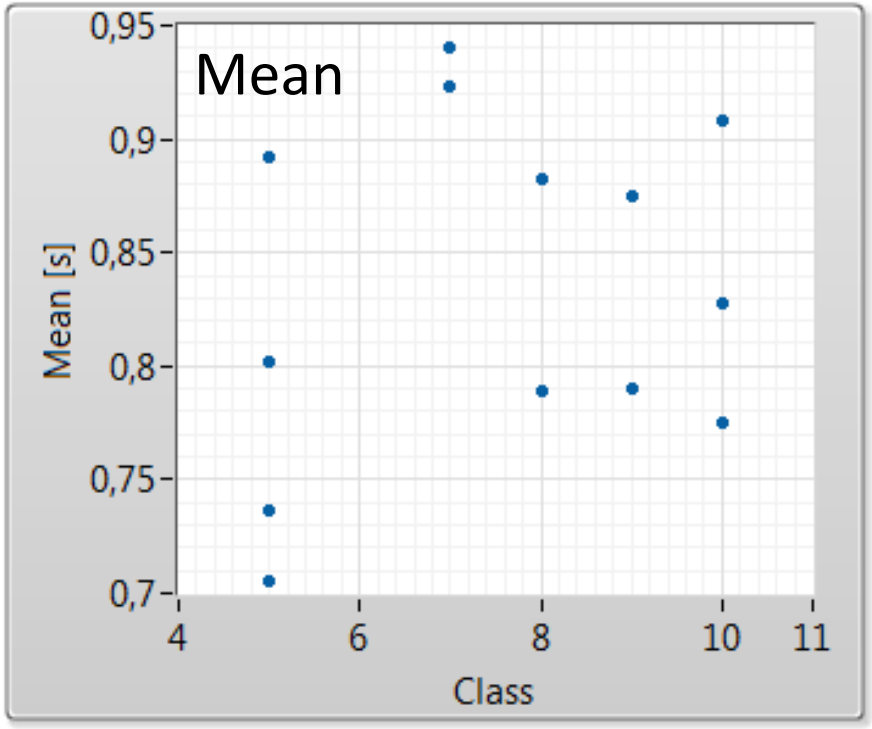


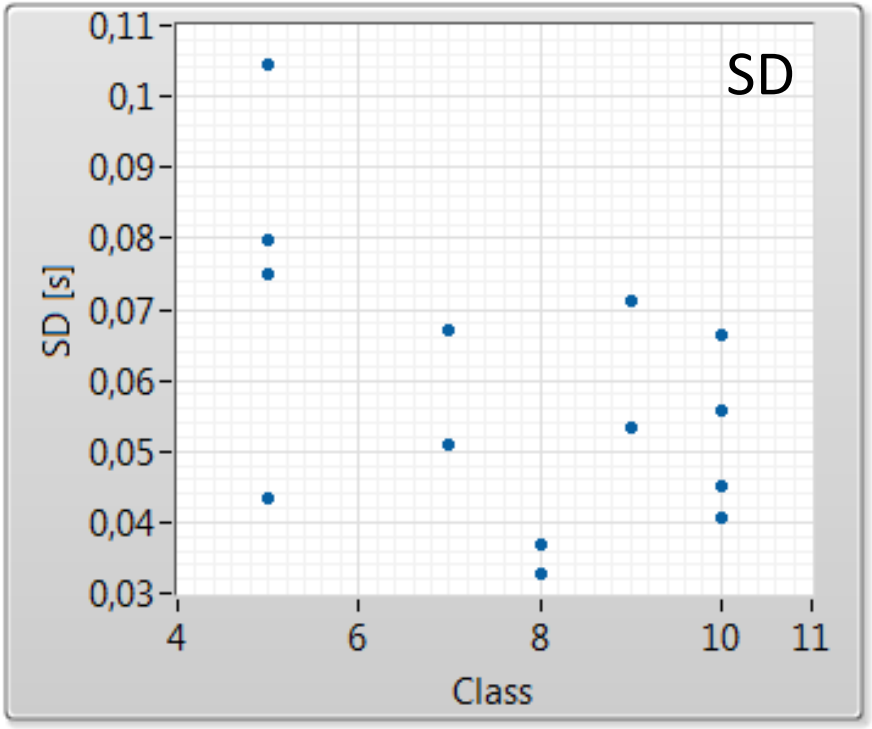


Temporal indicators



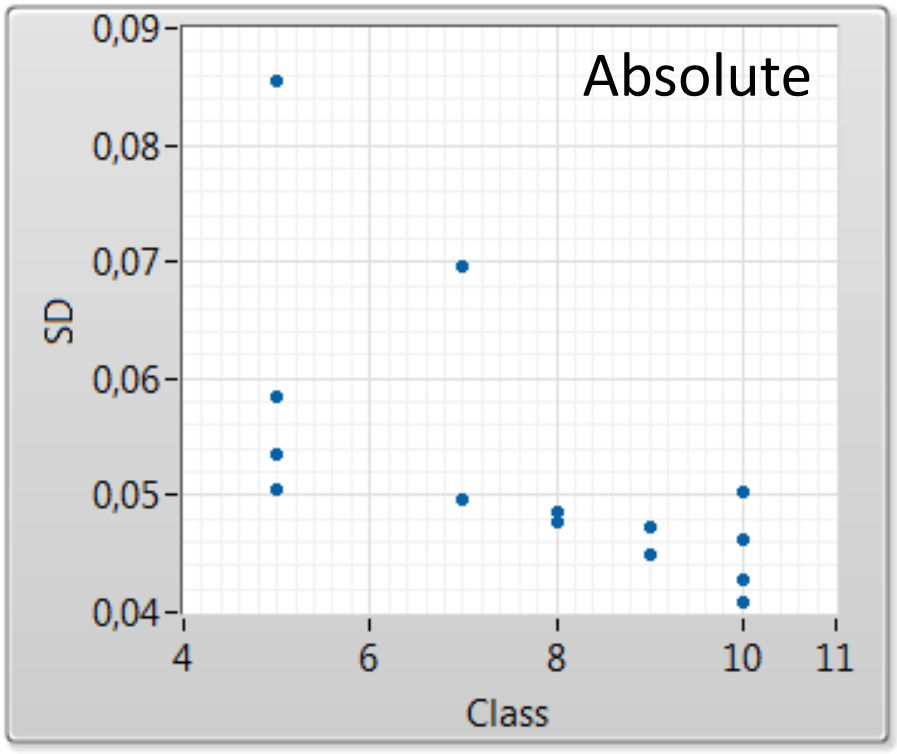
- Stroke time

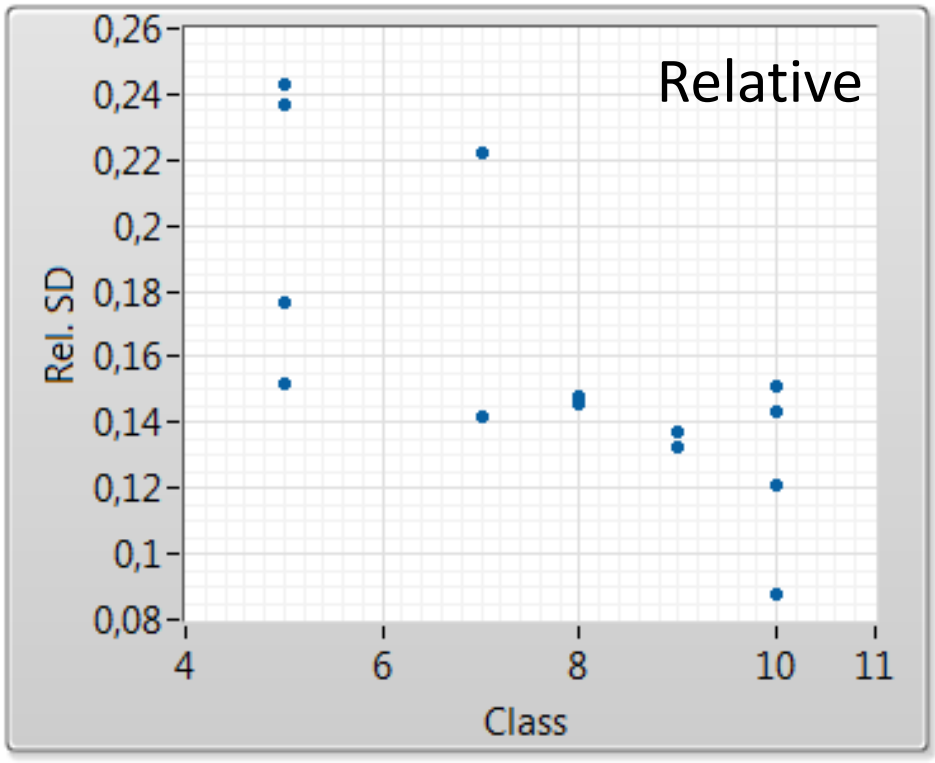




Relative SD?

- Normalized to mean value
- Stroke impulse:



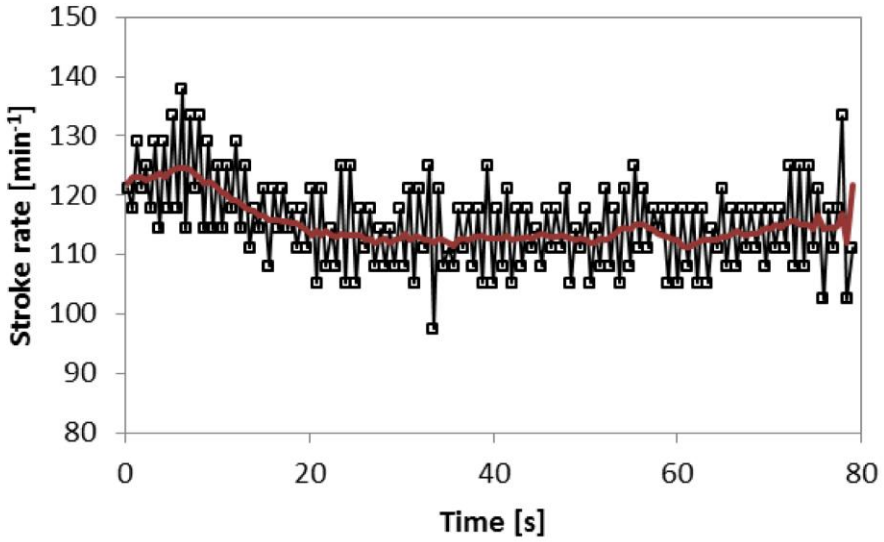


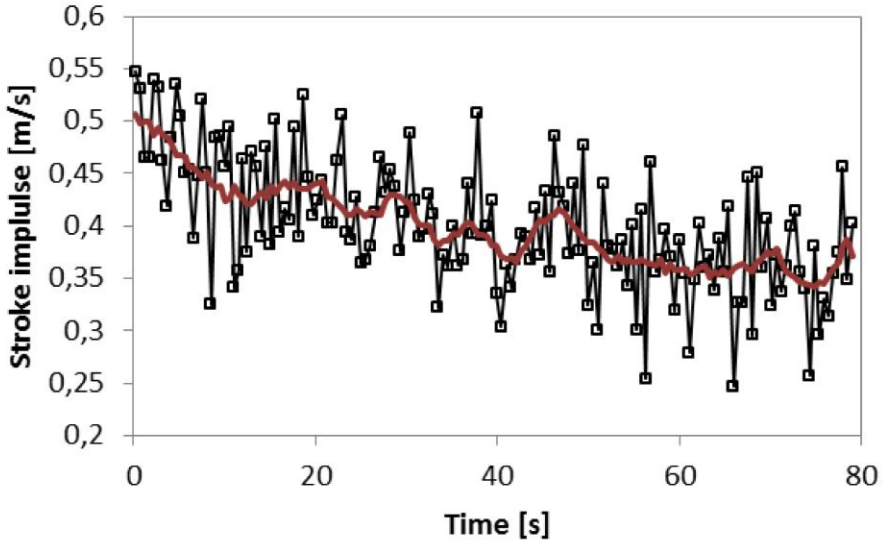
- No significant difference

Detrending?

- Slow changes
  - Strategy
  - Tiredness
- Detrending?

500 m race

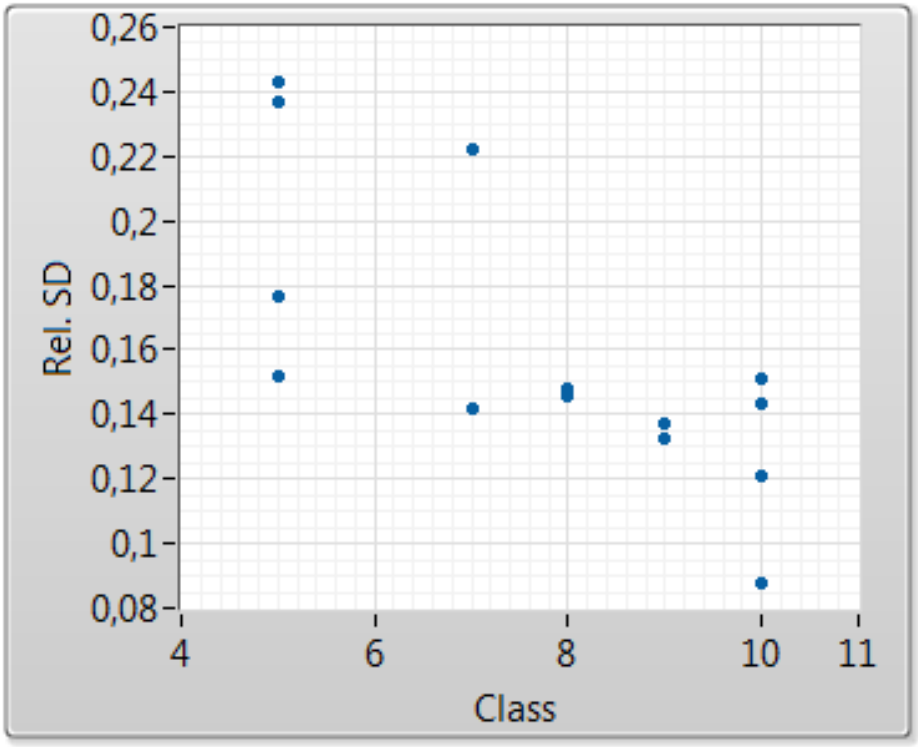


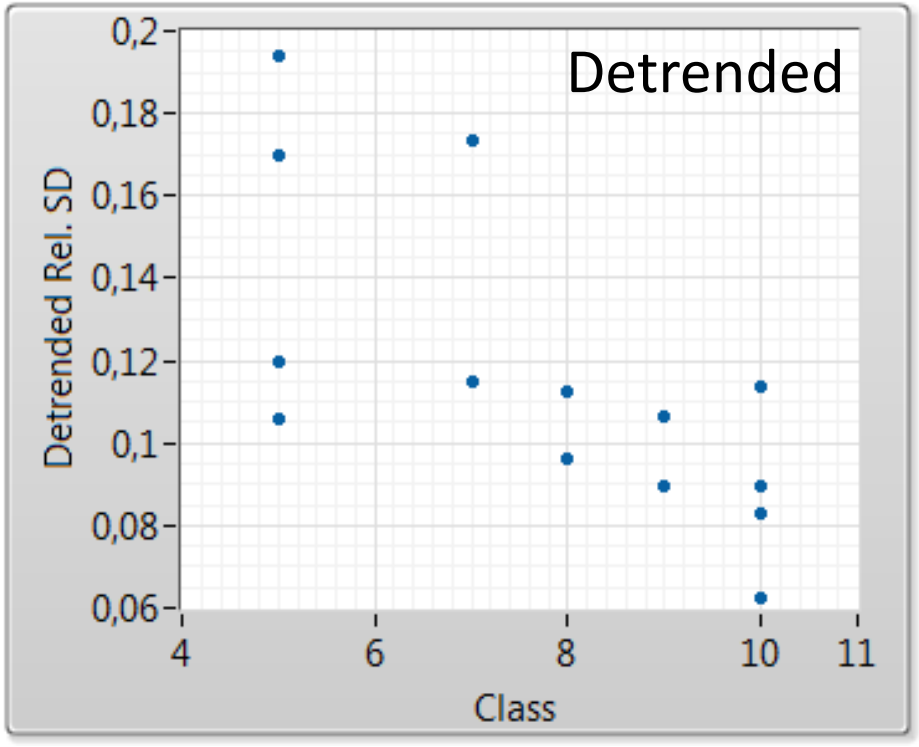


[1] G. Vadai et al. in 36th Int. Conv., Microelectronics, Electronics and Electronic Tech. 2013, pp. 144-149.

Detrending?

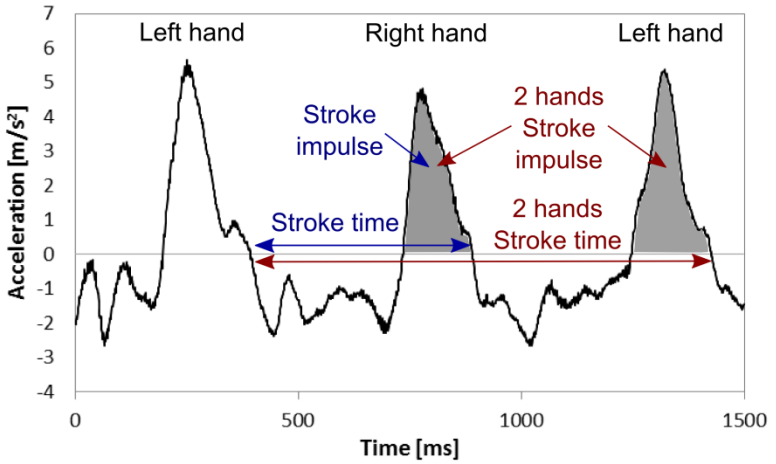
- Detrending using digital highpass filter
- Relative stroke impulse:

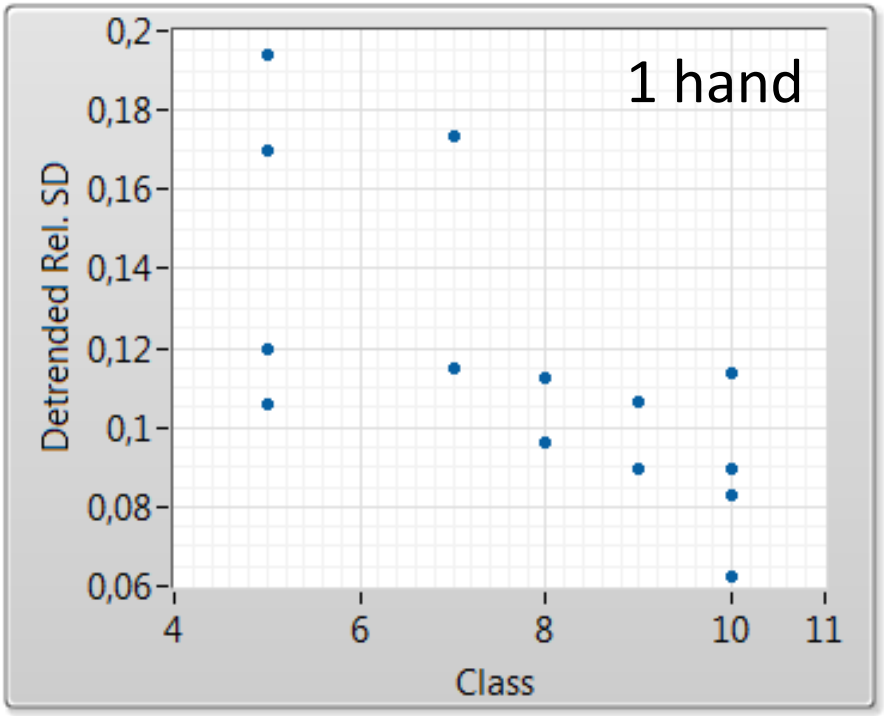


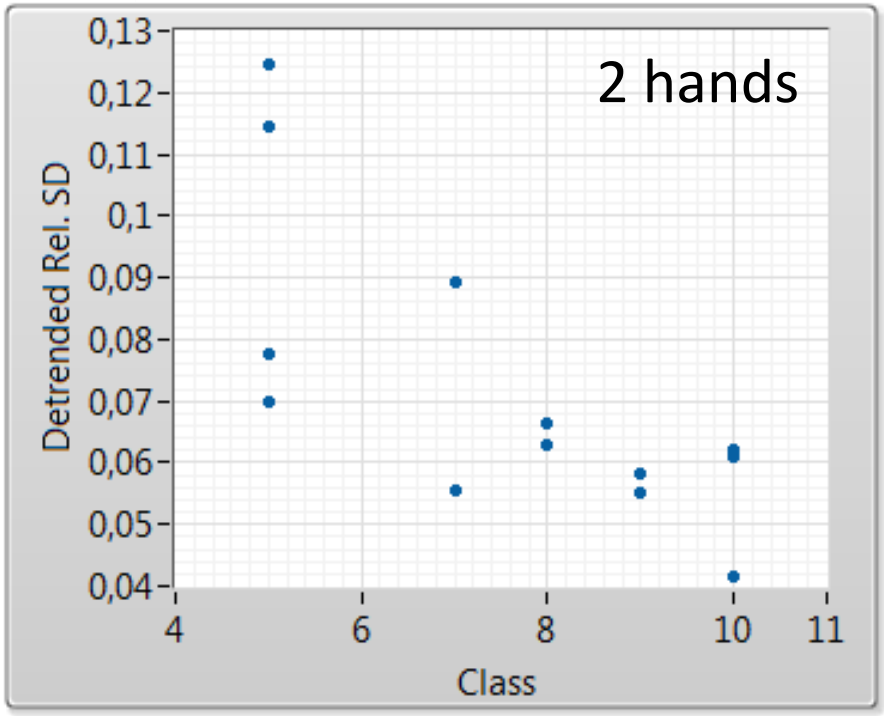


One hand – two hands

- **Stroke impulse** calculated
  - One pulling
  - Sum of a pulling of right and left hand

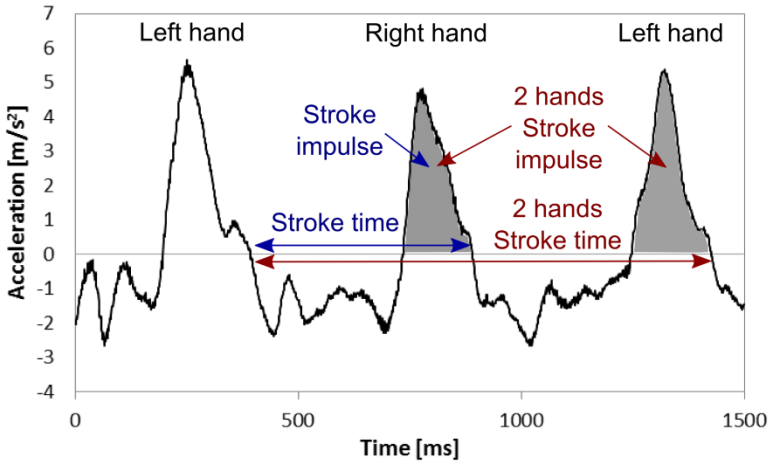


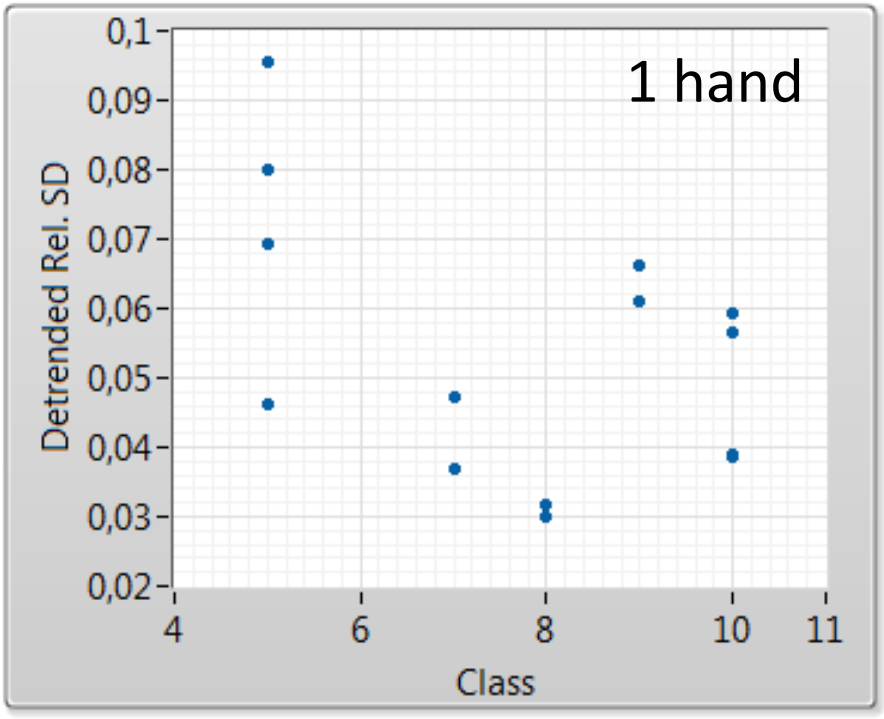


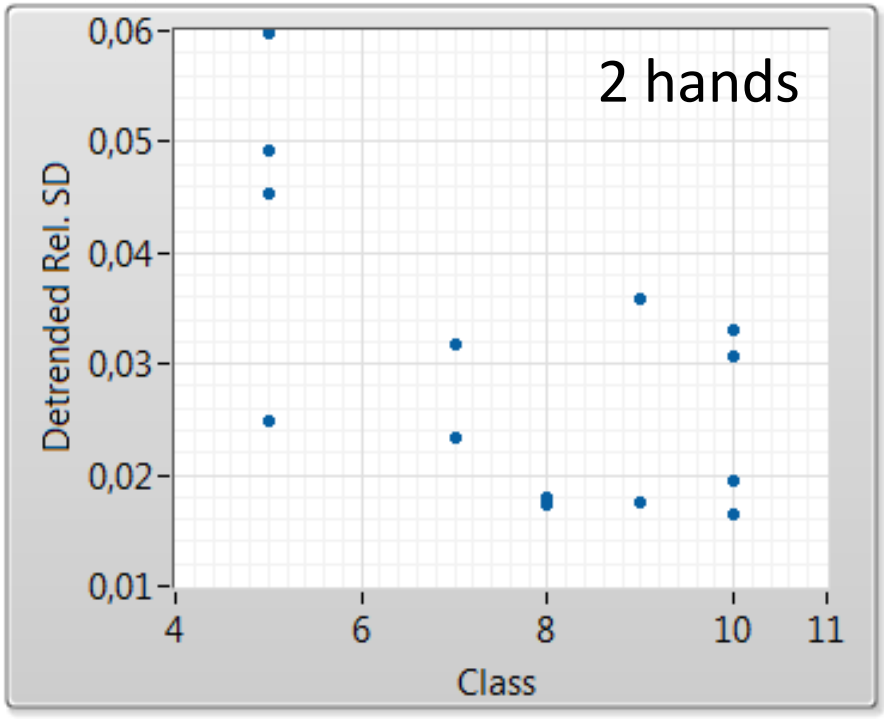


One hand – two hands

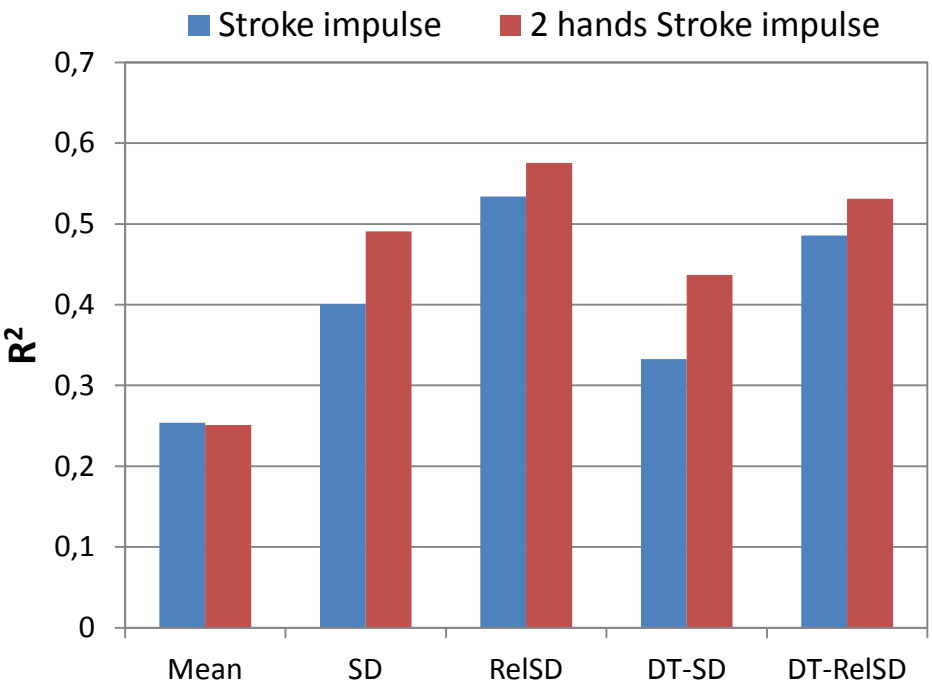
- **Stroke time** calculated for
  - One pulling
  - Sum of a pulling of right and left hand

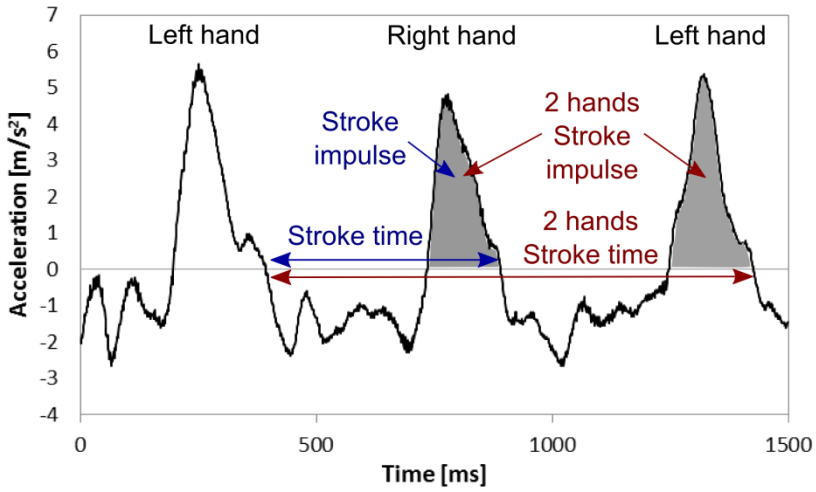


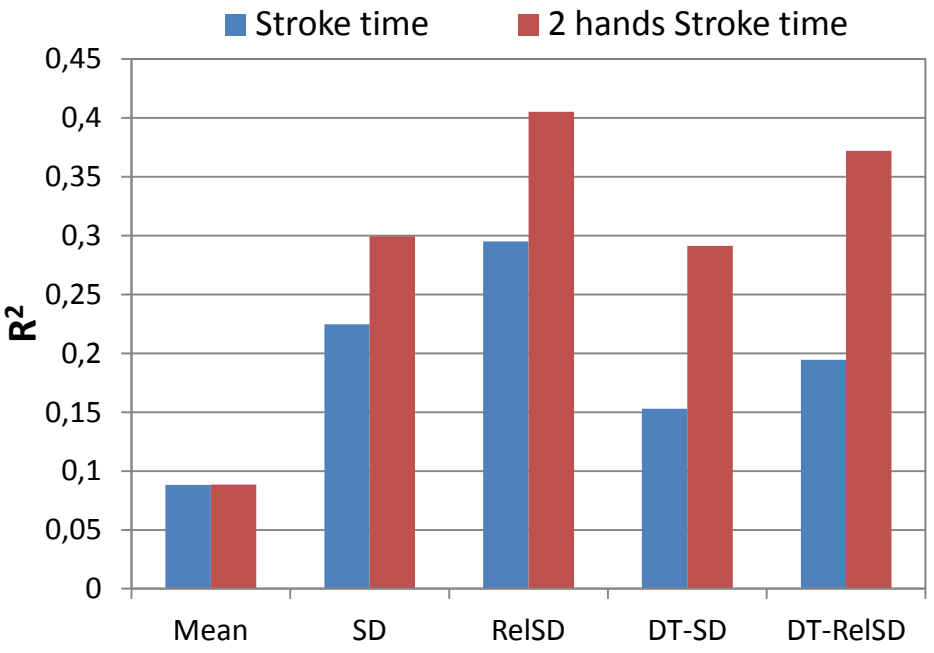




How it correlates with the classification?







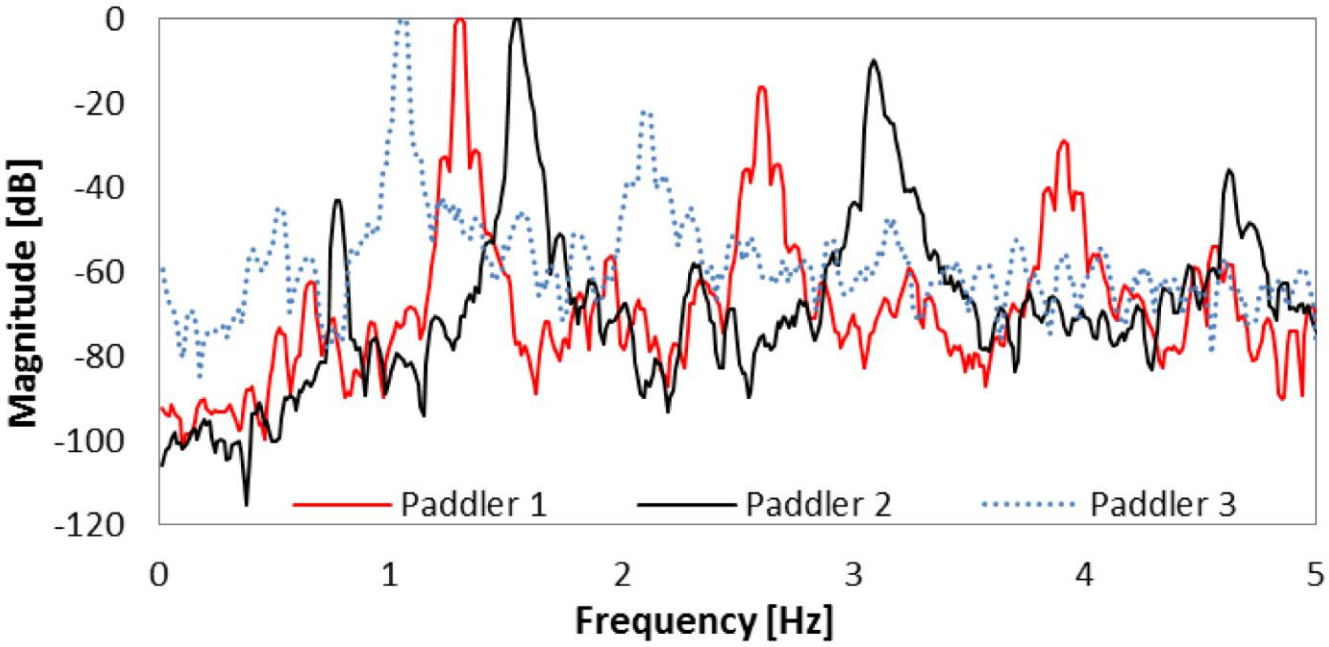
R^2: indicator value vs class

Spectral analysis of raw signals

- In many cases (sprint race, transients, vibration)
  - signals are more complex
  - detection is difficult
- ***Can we eliminate the detecting algorithms and associated problems?***
- Determining indicators from the raw movement signals?
- Avoiding using complex and less reliable detecting algorithms?

Power spectral density

- **X-axis acceleration** PSD



World Champion

Professional athlete (assymetric style)

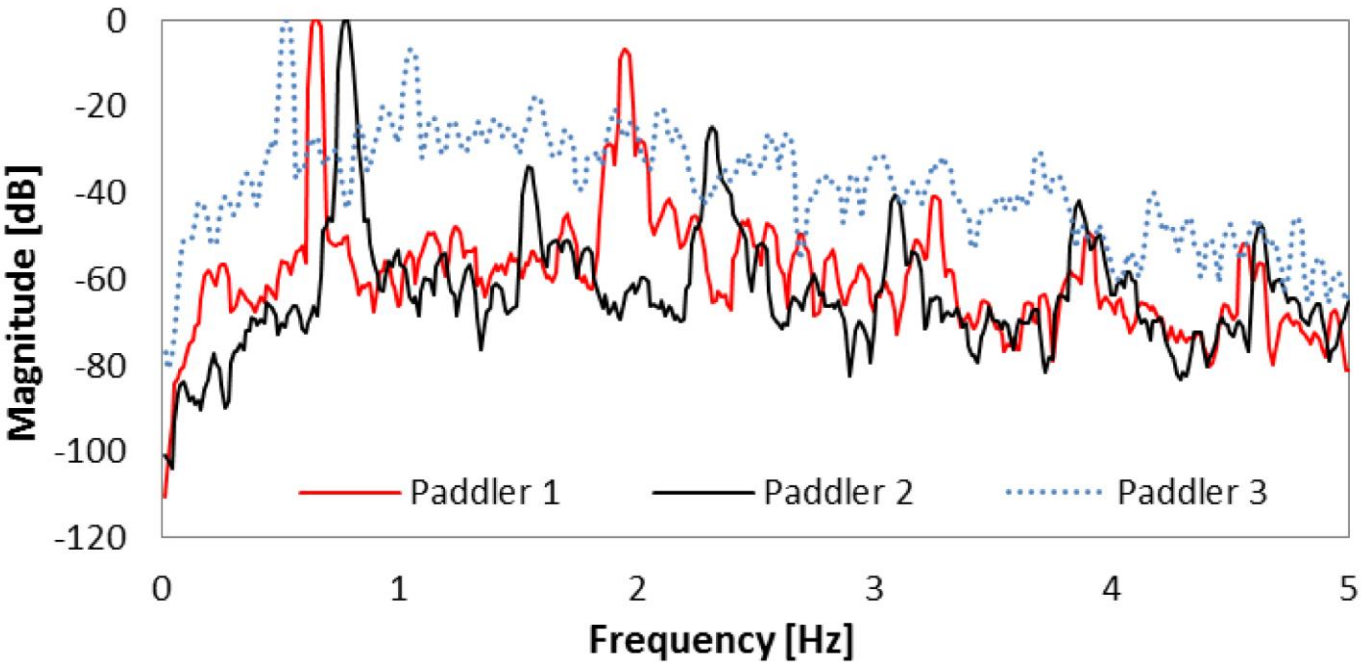
Beginner (13 years old)

- Dominant frequency: **first harmonic**
  (belongs to one stroke cycle regardless of pulling hand)

[2] G. Vadai et al. In 22nd International Conference on Noise and Fluctuations, 2013, Paper 6579010.

Power spectral density

- **Angular velocity (roll)** PSD – better selectivity



World Champion

Professional athlete (assymetric style)

Beginner (13 years old)

- Dominant frequency: **fundamental frequency** (belongs to the sum of a right and a left hands stroke time)

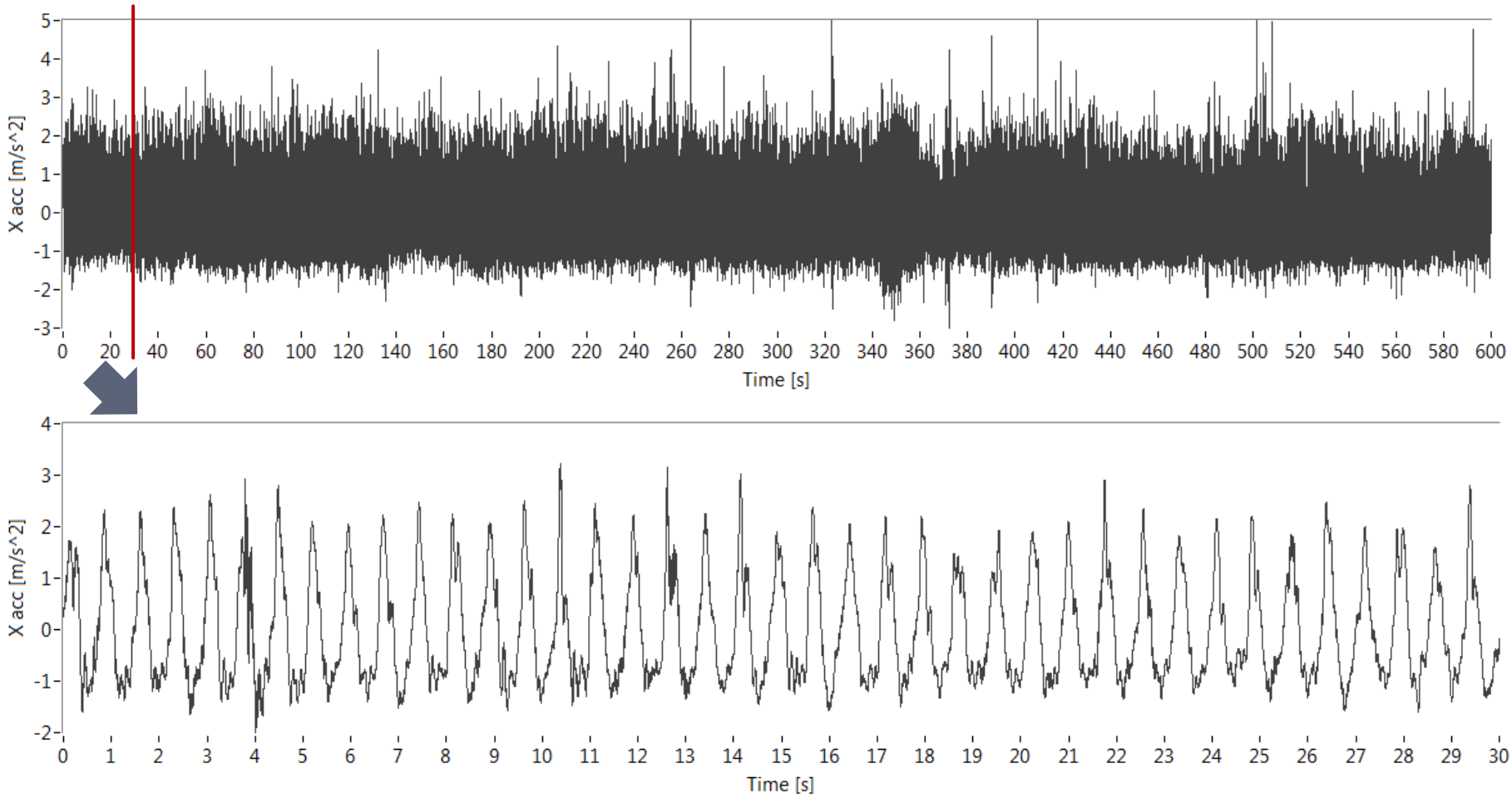
[2] G. Vadai et al. In 22nd International Conference on Noise and Fluctuations, 2013, Paper 6579010.

Spectral indicators

- Possible indicators of performance:
  - Signal level and noise level
  - SNR – signal-to-noise ratio
- How can we separate „signal” and „noise” in the spectra?

- PSD calculation:
  - Window length?
    (Same question for temporal case)
  - Window function?

Spectral analysis



PSD calculation → Detecting harmonics → SNR
Signal level
Noise level → Averaging for 10 min (20 windows)

Decomposition

- **Signal:** harmonic peaks
  - Number of peaks? (first 2 and first 6 used)
- **Noise:** other parts of the spectra

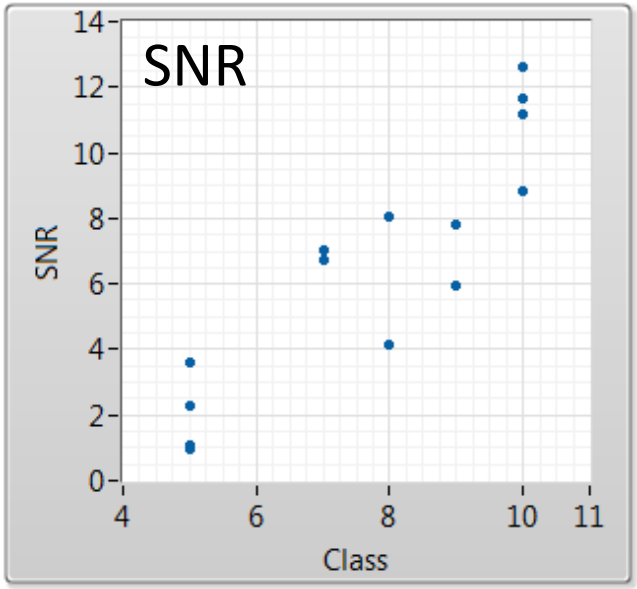
- Numerical solutions
  - How should we separate the peaks?
  - Universal method needed
- Two types of signals:
  - Periodic with every pulling (X acc, Z acc, Pitch)
  - Periodic with every 2 pullings (Y acc, Yaw, **Roll**)

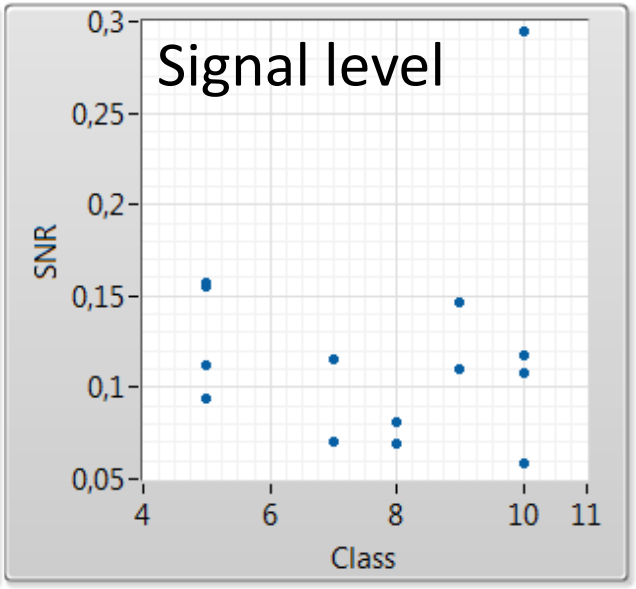
Numerical methods

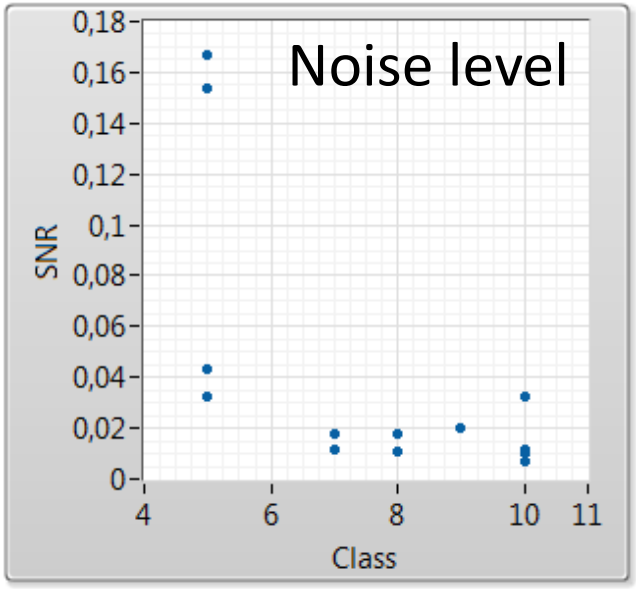
- We define a fix peak width: 0,2 Hz
  - Max of PSD magnitude ± 0,1 Hz + harmonics
- Detecting half width of dominant peak
  - Max of PSD magnitude ± 0,1 Hz + harmonics
- Multiply this width at higher harmonics?
- Half width of peaks

Spectral Indicators

- SNR, signal and noise level

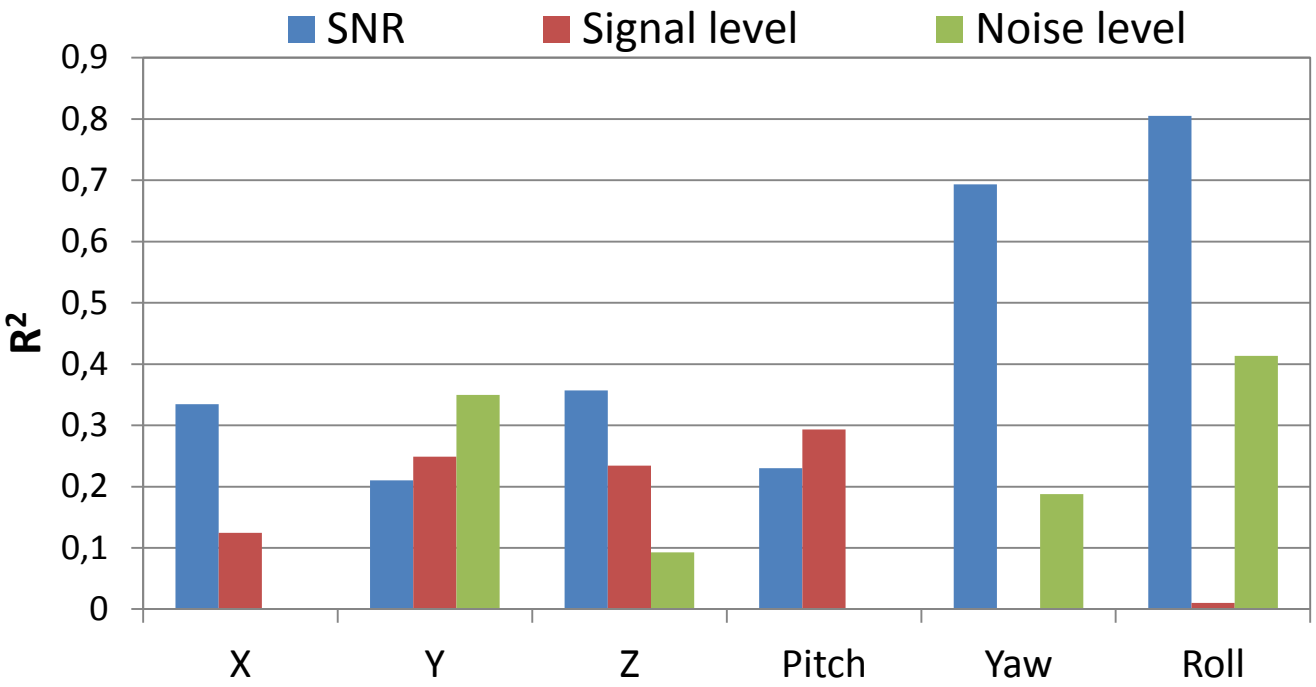






- Angular velocity (Roll), 6 peaks, 0,2 Hz fix width, Hanning window

Spectral Indicators

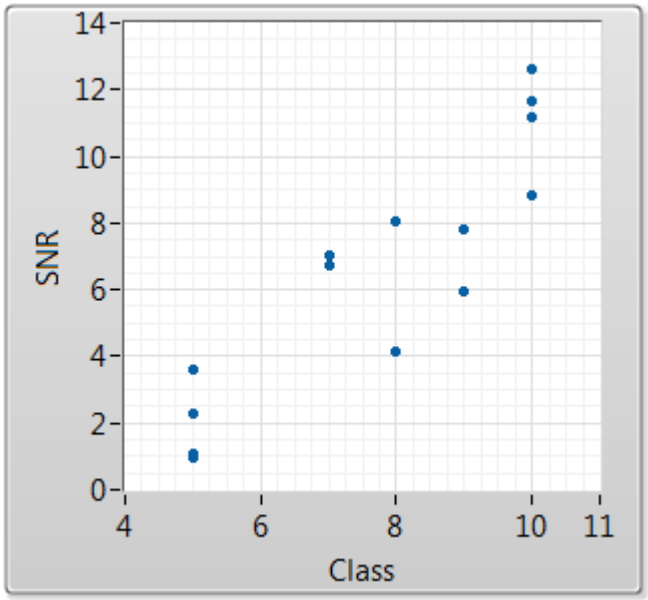


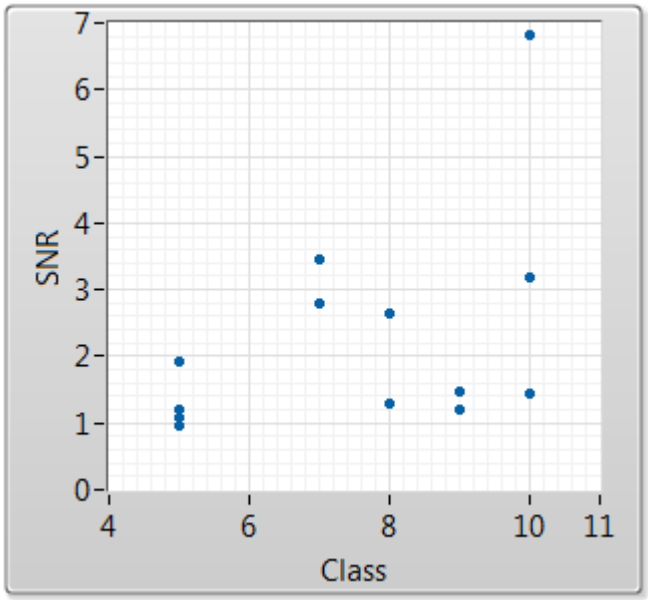
6 peaks
0,2 Hz fix width
Hanning window

- SNR and Noise level can be used
- **SNR is the best**
- Yaw and Roll Gyroscope signals
  - Fundamental freq – pullings with 2 hands

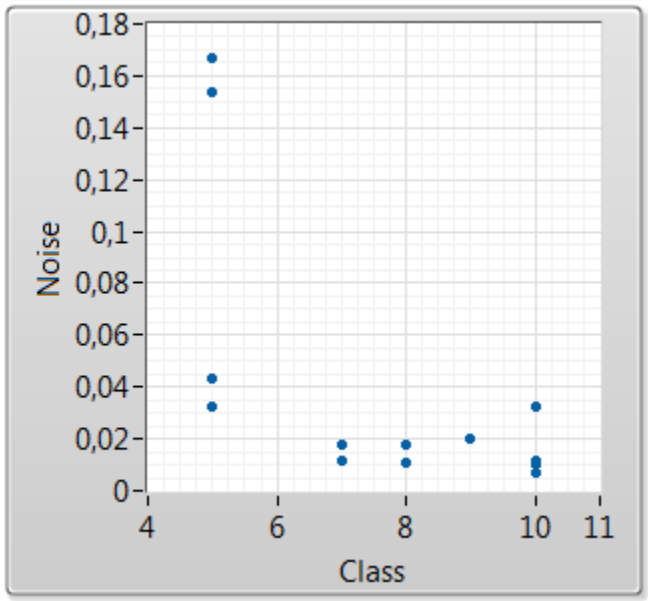
Number of harmonics – 6 is better

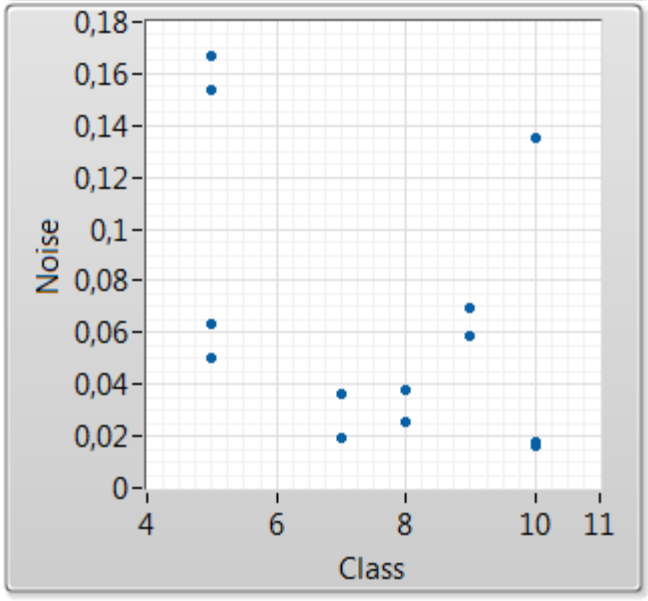
6 peaks





2 peaks





Remarks, open problems

- We have used time and frequency domain fluctuation analysis to find new indicators
  - Higher performance is related to higher SNR
  - Signal and noise separation
  - Certain time window length used
  - Comparison of parameters, athletes' performance
- There can be better indicators, more detailed analysis, more data are needed
- How can we reliably test the indicators or numerical methods?
  - Age, class, race time…

Remarks, open problems

- Fundamental frequency = dominant frequency
  - Steadiness of motion seems to have a primary role
- Performance depends on many other factors
  - How reliably the indicators can be used in certain cases?
- What are the sources of noise?
  - Mechanical sources
  - Applied paddling technique
  - Others?
- Are the fluctuations related to mental condition?

Remarks, open problems

- Simulations may help
  - Testing indicators, algoritmhs
  - Creating models, theoratical discuisson
- Is the method general enough for other fields?
  - Performance, reliability analysis
  - Periodic motions: several other sports
  - Neurology related experiments
  - Actigraphy
- Can smart phones be used in similar investigations?

The publication is supported by the European Union and co-funded by the European Social Fund.

Project
title: “Telemedicine-focused research activities on the field of Mathematics, Informatics and Medical sciences”
Project
number: TÁMOP-4.2.2.A-11/1/KONV-2012-0073.

National Development Agency
www.ujszechenyiterv.gov.hu
06 40 638 638

The project is supported by the European Union and co-financed by the European Social Fund.