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

Gergely Vadai[1] and Zoltán Gingl[1]
[1]*Department of Technical Informatics, University of Szeged, Szeged-6720, Hungary*
e-mail address: vadaig@inf.u-szeged.hu ; gingl@inf.u-szeged.hu

I. INTRODUCTION

In several cases periodic signals shape, period have some fluctuations that can be informative. From periodically working machines to heart movements the variability can be used to know more about proper behavior[1]. Nowadays several devices – like smart watches, wrist-bands, smart phones, actigraphs – can measure movements, motion patterns by inertial sensors for several applications including monitoring daily activity cycles for health analysis.

Similar inertial sensors are used in coaching devices developed for professional kayak paddlers and trainers, where classical parameters, quantities and their shape in one stroke cycle are used to classify the athletes performance[2-4]. In a previous work we have shown that because the optimal motion of a kayak is clearly periodic, therefore the fluctuations of its period could be an indicator of athletes' performance[5]. We have calculated a signal-to-noise ratio using the raw signals' spectra and it seemed to be a good indicator too and it does not require the detection of strokes.

As we show hereinafter, more detailed analysis needed to examine the relationship between these fluctuations and paddlers performance, many questions are still open about how one should define and calculate the temporal and spectral indicators, how these fluctuation based indicators can be used to classify similar periodic processes.

II. KAYAK MOTION DATA

The examined motion signals of the kayaks were measured by a special portable instrument developed in our laboratory. The device recorded the 3-axis acceleration and 3-axis angular velocities of the kayak with a sample rate of 1000 Hz[5,6].

Our goal was to find the best indicators of athletes' performance based on a classification done by the trainer. In order to compare the typical performance of paddlers in the same circumstances (as much as possible), we have analysed the first 10 minutes of long range (>5 km) training paddling of 14 athletes with different age and technical skills.

The fluctuation-based indicators (time or frequency domain based both) were calculated for shorter window lengths (30 seconds in figures), and the averages for the examined 10 minutes long part were compared.

III. TEMPORAL INDICATORS

The classical parameters of stroke cycles (stroke time, stroke impulse etc.) were calculated by peak and level crossing detection algorithms, using the forward axis acceleration signal[6].

As we have pointed out in previous works[5,6], not only the mean values of these parameters, but their fluctuations can also give information about athletes' performance. As it is shown on Fig. (1), the relative standard deviation (SD) of the stroke impulse and the period decreases with better class significantly.

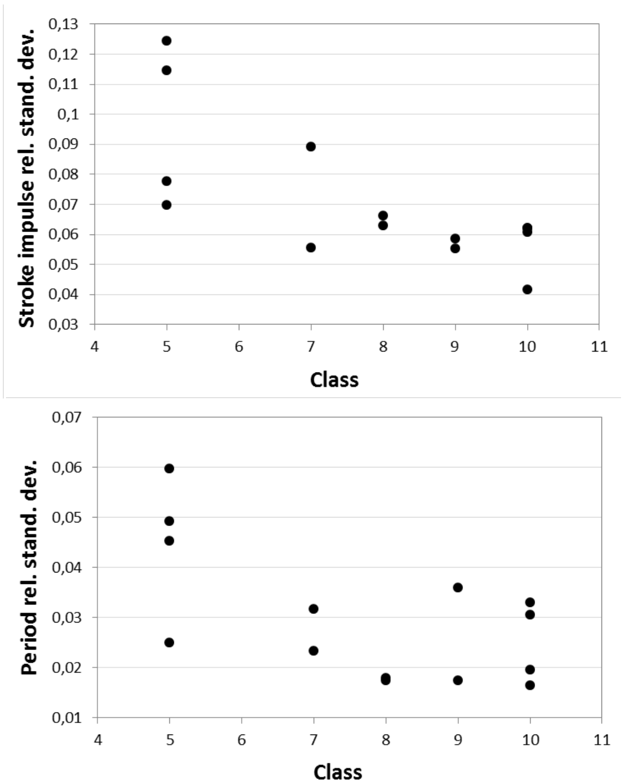

FIG. 1. Relative standard deviation of the detrended stroke impulse and period in the function of technical skills' classification (higher number is better). The parameters were calculated for whole periods (total duration of a left and a right hands stroke).

On the other hand, there are some open questions about how we should calculate these SDs. Changing stroke rate and effects of tiredness can be observed in every paddling, so the length of the processed data and using detrending algorithms could have impact on the indicators' values and the their observed relationship with technical skills. Furthermore, calculating absolute or relative SDs, defining the motions period as one stroke cycle or the sum of a left and a right hands stroke could affect this relationship, too.

IV. SPECTRAL INDICATORS

Precisely detecting the strokes using the complex signals with additional irregularities and noise could be rather complicated and inaccurate in most cases. Therefore calculating indicators based on the spectra of raw signals has many advantages concerning the signal processing. Note that it can be even extended to joint time-frequency analysis. Following this we have used a certain kind of signal-to-noise ratio (SNR) as another possible indicator for performance estimation[5].

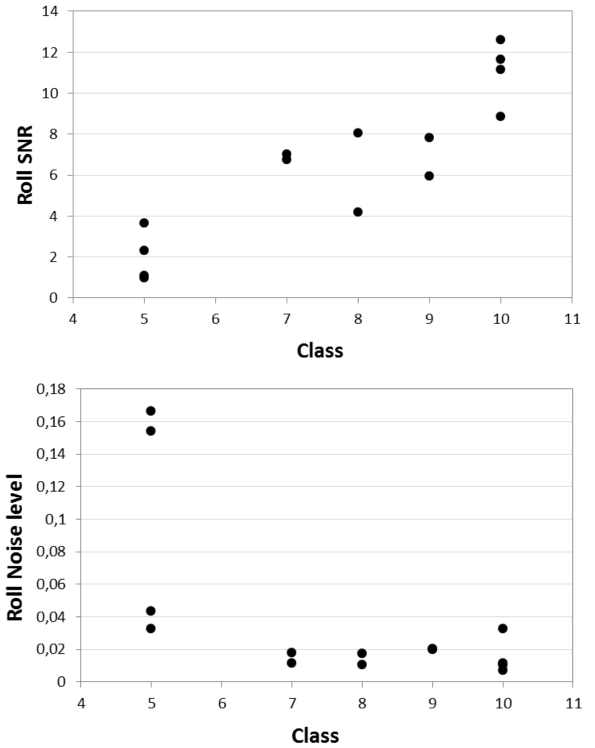

FIG. 2. Signal to noise ratio (SNR) and noise level of roll axis angular velocity as a function of technical skills' classification. Signal level of the spectrum were defined as the power of 0.2 Hz width peaks on fundamental frequency and first 5 harmonic frequencies, while the noise level was the power of the rest of the spectrum.

One of the most important question is how one can separate the "signal" and the "noise" in the power density spectra. In case of one acceleration and two gyroscope signals, the dominant frequency is the first harmonic (belongs to one stroke cycle), but the in the case of the other three signals, the fundamental frequency is more significant (belongs to the period of both hands strokes). Consequently there are several ways to calculate SNRs. Also, beyond the ratio, the signal and noise levels could be indicators as well.

Detecting the peaks precisely is not simple at all. We have designed numerical methods for finding the signal power in the spectra based on fixed peak or estimated half-width, and we have used them in different signal and noise definitions. We have compared all of these results for different window length and types.

We found that estimating the signal level precisely is rather difficult, however the noise level alone seems to be a usable indicator of the technical skills as well. As depicted on Fig. (2) a certain type of SNR (details can be found in the caption) and noise level both show strong relationship with the technical quality.

V. OPEN PROBLEMS

As we have already pointed out, there are many questions about how we should calculate the temporal and spectral indicators. We present several different definitions for SNR, signal and noise level and simple algorithms to calculate them using six inertial sensors' signals.

The fact that the spectral indicators worked only for the signals whose dominant frequency is the fundamental frequency, and the temporal indicators also were better when the period was the sum of a left and a right hands stroke implies that the steadiness of the motion has a primary role in the paddling quality.

There can be other temporal parameters or spectral methods that can indicate the performance even better, so more detailed analysis is worth to be performed.

The indicators discussed above were tested using classification of technical skills, however the actual performance of the athlete depends on many factors. This is exceptionally important in order to determine how reliably the indicators can be used for certain cases, to determine what kind of data processing is needed.

Furthermore, it is an exciting question what are the sources of the noise can be detected in the paddling periodicity and strength. It can depend on mechanical effects – movement of the kayak and of the human body, dissipation –, learned technical skills and even mental condition, can be correlated to other processes.

Another interesting question is how this analysis can be related to other periodic motions, other sport fields, performance and reliability estimation, actigraphy or even more.

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