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Correlation of EMG activity and kinematics in case of ergometer rowing

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Abstract: This paper deals with the correlation of muscle activity represented by EMG signals and kinematic data recorded during indoor rowing. Experiment included simultaneous measurement of EMG activity of Vastus Medialis, Biceps and Gastrocnemius muscles and kinematic data acquisition by using the video motion tracking system. Video camera - PC system records positions of markers attached to 8 body points, in sagital plane. Four rowers with five, or more years rowing experience participated in the study. Processing of collected kinematics and EMG data were done in Matlab program package.

Key - Words: rowing, biomechanics, EMG, computer vision, signal processing

1 Introduction

One of the most important things in various human motion analyses is to know relationship between kinematics parameters which describe particular motion and the generators of that motion. In this case, human muscle or rather groups of muscles are chiefly those generators. Such information is very useful to the sport coaches, physiotherapists, kinesiologists, surgeons in their assessments.

One of the well known approaches for evaluation of that relation is so called inverse dynamics. If we have a full kinematics description, accurate anthropometric measures and the all external forces, we can calculate the joint reactions forces and muscle moments [1]. It is very useful but complex method which demands lots of calculus. On the other hand, quantitative relationship between motions of one particular segment of human body and muscles involved in its motion can be estimate cross correlated segment acceleration and EMG muscles activity. This paper deals with that method applied on the ergometer rowing example. The rowing has been chosen for the sake of rowing motion complexity (almost all major muscles are involved in that motion) and indoor signal acquisition possibility. Basic principles of this method rely on simultaneous measurement of EMG activity of particular muscles and 2D kinematics data acquisition.

2 Theoretical frameworks

Basic theoretical principle in human motion study is link segment model analysis and motion phase distribution.

In that sense, rowing stroke can be divided into the five basic phases [2]:

- Catch
- Drive
- Finish
- Release
- Recovery

It is important to know which muscles and in what volume participates in particular phase. If we know answer on that question, great possibilities for techniques improvement and injury prevention are opened. As we already mentioned in this article, rowing kinematics measurement and the surface EMG recording was done at the same time. For the purpose of the rowing stroke kinematics analysis simplified 2D link segment model has been given as it is shown on the Figure 1. Eight markers (M1 - M8) are attached on crucial body points and from their coordinates ((x_i, y_i), i = 1, 2, 3, …, 8) major parameters for rowing kinematics analysis were calculated according equations (1 - 5). Thereby, relative coordinate systems have been used at kinematics parameters definition.

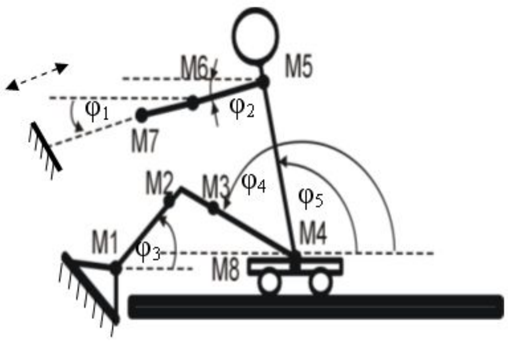

Fig. 1 Simplified 2D link segment model together with the wanted angels and the marker positions pointed out

$$\varphi_1 = arctg\frac{y_7 - y_6}{x_6 - x_7} \quad (1)$$

$$\varphi_2 = arctg\frac{y_6 - y_5}{x_5 - x_6} \quad (2)$$

$$\varphi_3 = arctg\frac{y_2 - y_1}{x_2 - x_1} \quad (3)$$

$$\varphi_4 = \pi - arctg\frac{y_3 - y_4}{x_4 - x_3} \quad (4)$$

$$\varphi_5 = \pi - arctg\frac{y_5 - y_4}{x_4 - x_5} \quad (5)$$

Numerical differentiation was done in Matlab in order to obtain linear and angular velocities and accelerations. Markers positions on body were obtained from anthropometrical tables [1] accordingly rowers high, weight, age and gender. These points were on ankle, lower leg, thigh, hip, shoulder, arm, wrist and one on ergometer seat. The following parameters for rowing kinematics analysis were observed in this way:

- Linear position, velocity and acceleration of ergometer seat
- Angular position, angular velocity and angular acceleration of the lower leg, thigh, trunk, upper arm and the forearm
- Wrist position, its velocity and acceleration
- Shoulder position in sagittal plane
- Shoulder position with respect to the seat
- Shoulder position with respect to the knee

The converted coordinates from recorded file contains noise signal from many sources - mostly VF signals (environment electronics and recorded equipment influence). Those signals are called RAW data. For the purpose of removing noise from RAW signals discrete Fourier transformation were performed in Matlab. First eight harmonics have been used for signal reconstruction. Number of harmonics was determined by the method of attempts and faults.

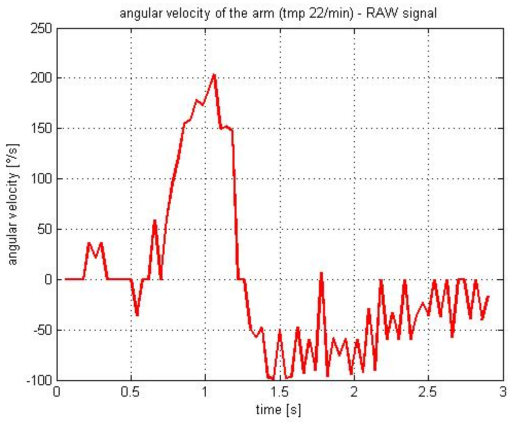

Fig. 2 Raw data - angular velocity of the arm

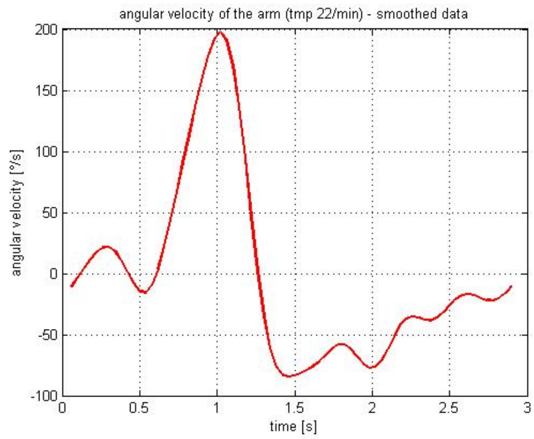

Fig. 3 Smoothed data - angular velocity of the arm

Besides kinematics recording, recording of EMG activity of three muscles (Biceps Brachii, Vastus Medialis and Gastrocnemius Caput Mediale) also was performed. Three electrodes were mounted on selected muscles (one per muscle). Before electrode placements, region of mounting were cleaned up with medical alcohol due to better conductivity. To prevent increasing of motion artefacts during rowing, surface electrodes also must be additionally ingrained. Secondly, whereby Vastus Medialis is one of four muscles of the Quadriceps, in order to eliminate possible appearing of the crosstalks, it's necessary to shift its electrode until one obtains maximum EMG signal response. After that, electrode has been mounted on that maximum response point. Threshold method has been used for defining intervals of muscle activity and inactivity. Maximum voluntary contraction (MVC) measurement represents basis of this method. MVC recording of all interested muscles, for every particular rower was obtained by recording electromyogram of maximal contraction during some few seconds. Average value of measured and rectified signal, obtained in this way, represents MVC and is express in μV. Electromyograms that we have measured on particular rowers have various values, so those can't be compared with each other. Therefore, they need to be normalized for the sake of comparison and statistical calculation [3]. Electromyograms normalization was done dividing amplitude of EMG signal in every instant of time with MVC value and it's than represented in percentage of MVC.

Acceleration of active body segments in the rowing stroke are caused by muscle activity. Calculated the cross correlation function between EMG activity and body segment acceleration we can identify the role of the specific muscle in generation of body segment movement during rowing.

3 Experimental procedure

The acquisition of EMG signals has been done by Bagnoli – 4 EMG System (Delsys) with differential surface electrodes [4]. Only three channels have been used – one for the recording Biceps Brachii, the one for Vastus Medialis and the third for Gastrocnemius Caput Mediale. Recording was done on the sample of 4 rowers with more than five years of active rowing. Each rower rowed a three minutes section - whole section on +10 seconds of 6000 m test average pace. Sampling frequency was 1000 Hz and data acquisition was done in whole 3 min section. Collecting of RAW EMG signal was done with EMGWorks v 3.0 software and 16 – bit A/D card National Instruments 6034E. In this way we have obtained EMG data files of RAW signals. Afterwards, conversion of those files in format appropriate for processing in Matlab program package was done with the program EMG Converter which is main part of the mentioned software and it is placed under its Tools menu.

Processing data in Matlab included the wavelets method of denoising [5] and defining average envelope of the rectified signal. Simultaneously with EMG recording, recording of the stroke kinematics in sagittal plane using marker method [11] is performed by a camcorder SONY DCR – TRV12E (in general any digital camcorder can be used), so we can define intervals of muscle activity and inactivity in particular stroke phase. For the kinematics data acquisition same computer with AMD ATHLON 750MHz processor and an external TV card with a video input has been used (also recorded video data can be transferred in PC trough USB port if used camcorder has a such possibility and appropriate acquisition software) [12].

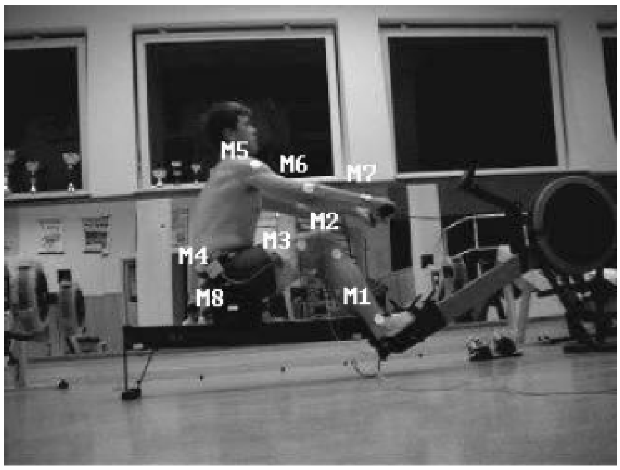

Fig. 4 Rower with markers positions pointed out

Marker tracking was done by program written in C++ which elaborated recorded video and produced a Matlab compatible file (matrix) containing coordinates of each marker recording throughout the time. This program is able to use different types of correlation or Walsh transform to follow selected markers on sequence of frames. It also relies on simple prediction of next position of marker. The markers were placed on each rower, from whose coordinates, the figures necessary for the kinematics analysis of the stroke were obtained (Figure 4).

4 Results and discussion

Previously described experimental procedure is very suitable for two things:

1) Detections of intervals of muscle activity / inactivity in all sports, especially in sports with repetitive motion path (like cycling, swimming, rowing, running etc.)
2) Estimating contribution of particular muscles in body segment acceleration - principle of cross correlation

One particular rowing stroke was extracted from three minute video shot in order to define time duration of selected stroke and corresponding EMG signals. Synchronous recording rowing stroke kinematics and EMG activity insure time instantaneity of these two events. In other words, 2D kinematics analysis provides information about mentioned kinematics parameters and time duration of each stroke phase.

Like collected kinematics data, EMG recorded data represents RAW signals. Information carrier is buried in recorded EMG signals because of the existence of white noise and motion artifacts. Recorded equipment influence and environment influence was minimized by using commercial equipment which is constructed with quality electronics components. Also, all cables are specially armored to prevent outside electromagnetic fields impact.

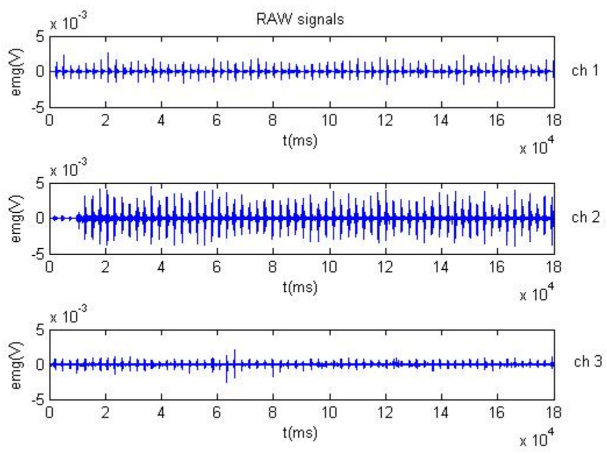

Fig. 5 RAW EMG signals of Biceps Brachii (ch 1), Vastus Medialis (ch 2) and Medial Gastrocnemius (ch 3)

EMG signal filtering was done in Matlab program package with wavelets method (denoising and artifact removing). The goal is to obtain rectified and normalized envelope of EMG signals filtered with wavelets method [7]. Thus processed signals are suitable for using threshold method for determination of intervals of muscle activity and for correlation process due to muscle contribution estimation [9]. On all following figures signals for Biceps Brachii (chanenel 1), Vastus Medialis (channel 2) and Medial Gastrocnemius (channel 3) have been shown in serial. Henceforth, all graphically depicted data represents average value of the EMG data of the four rowers from the test group - mean value of the all matrix data.

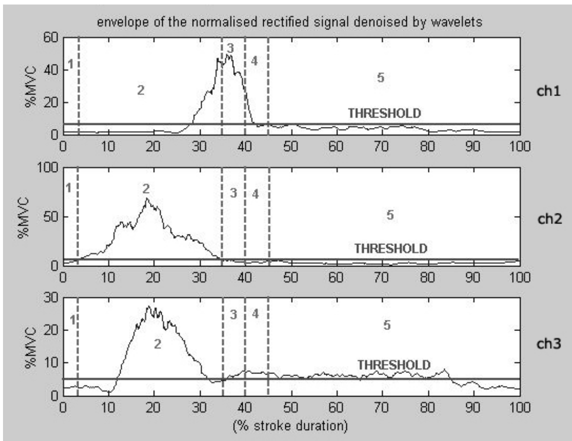

Fig. 6 Processed EMG signals during one rowing stroke - Biceps Brachii (ch 1); Vastus Medialis (ch 2); Medial Gastrocnemius (ch 3)

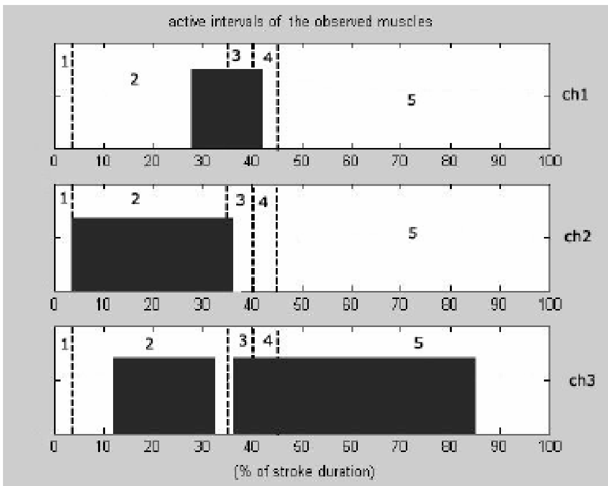

Fig. 7 active intervals of Biceps Brachii, Vastus Medialis and Medial Gastrocnemius during one rowing stroke

Numbers (1 - 5) on above figures (Figure 6 and 7) represents five basic phases of the rowing stroke (1 - Catch; 2 - Drive; 3 - Finish; 4 - Release; 5 - Recovery). Per threshold method all normalized EMG values that are less than chosen threshold considered as intervals of muscle inactivity. Also, all values greater than that threshold can be considered as a active muscle phase. Five percent of MVC value has been defined as threshold value and it's pointed out on Figure 6. Accordingly literature, all active intervals whose duration are less than 5% of duration of whole stroke cycle can be ignored and considered as EMG activity with no functional significance [6], [8,9]. Figure 7 represents obtained active intervals of observed three muscles during one rowing stroke.

Muscle activity (ON - OFF state) in particular stroke phase and duration of that activity in percentage of duration of each stroke phase can be assessed from the previous Figure 7 [12]. In table one, those intervals of three chosen muscles have been shown.

Table 1 - Intervals of muscle activity of selected muscles and their percentage participation in duration of each stroke phase

	catch (1)	drive (2)	finish (3)	release (4)	recovery (5)
Biceps Brachii	0,0%	22,9%	100,0%	46,0%	0,0%
Vastus Medialis	0,0%	100,0%	25,0%	0,0%	0,0%
Medial Gastrocnemius	0,0%	63,7%	78,0%	100,0%	72,7%

Finally, contribution of particular muscle in body segment acceleration has been defined cross correlated processed EMG signal with body segment acceleration. Cross correlation has been performed in Matlab using embedded function xcorr scaling with parameter 'coef'. That scaling insures maximal value of one for correlation at zero lag.

Obtained results for cross correlation have been verified with cross correlation in frequency domain using Discret Fourier transformation. Definition for cross correlation in frequency domain is [10]:

$$CORR = X(f) \cdot Y^{*}(f)$$

Or, in Matlab notation:

CORR = X(f).*conj(Y(f))

Inverse transformation of CORR is giving a result which can be compared with previously one - cross correlation in time domain. Following figures representing signals for cross correlation analysis:

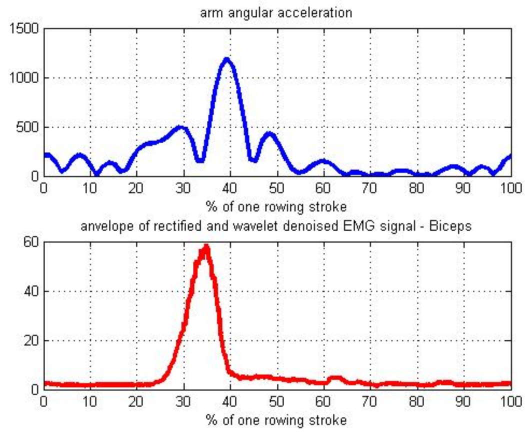

Fig. 8 arm angular acceleration and envelope of Biceps

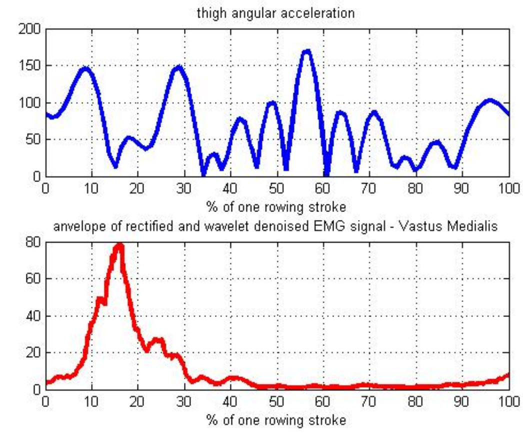

Fig. 9 thigh angular acceleration and Vastus envelope

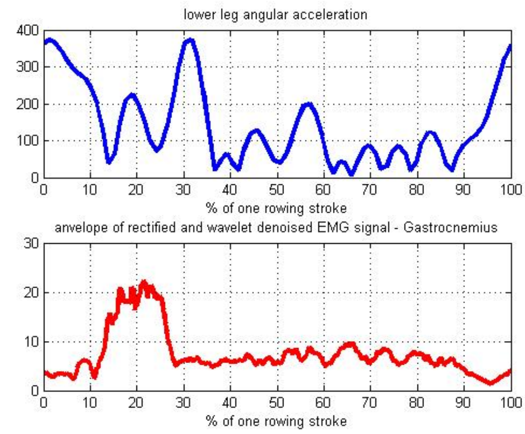

Fig. 10 lower leg angular acceleration and Gastrocnemius envelope

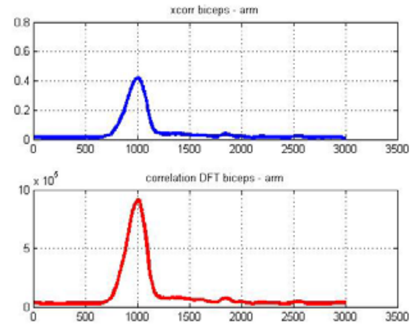

Fig. 11 cross correlation result comparison (xcorr –DFT) for biceps EMG and arm angular acceleration

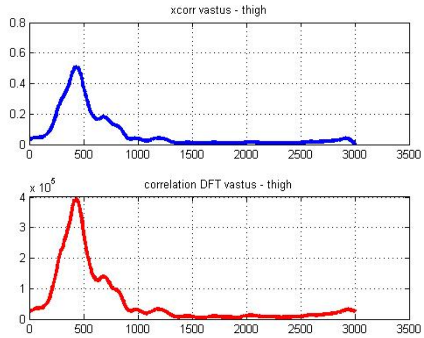

Fig. 12 cross correlation result comparison (xcorr – DFT) for vastus medialis EMG and thigh angular acceleration

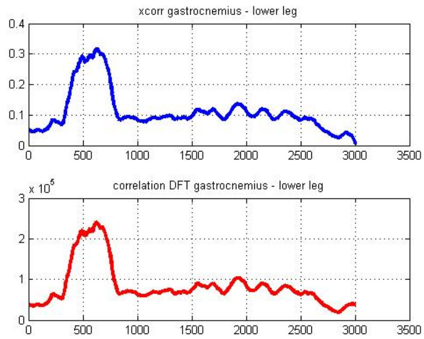

Fig. 13 cross correlation results comparison (xcorr – DFT) for medial gastrocnemius EMG and lower leg angular acceleration

5 Conclusion

Described method of simultaneously recording rowing kinematics in sagittal plane and muscles EMG activity is presenting very useful tool for detection of active muscle intervals in particular rowing phase and for defining muscle contribution in generation of body segment acceleration. Thus, great possibilities are opening for coaches, kinesiologies, physiologist etc. in sense of their assessment improvement. Also, this method is applicable in study of others human movements.

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