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Expert rowers' motion analysis for synthesis and technique digitalization

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Abstract

Four expert rowers' gestures were gathered on the SPRINT rowing platform with the aid of an optic motion tracking system. Data were analyzed in order to get a digital representation of the features involved in rowing. Moreover, these data provide a dataset for developing digital models for rowing motion synthesis. Rowers were modeled as kinematic chains, data were processed in order to get position and orientation of upper body limbs. This representation was combined with SPRINT data in order to evaluate features found in the literature, to find new ones and to build models for the generation of rowing motion. The analysis shows the effectiveness of the motion reconstruction and two examples of technique features: stroke timing and upper limbs orientation during the finish phase.

1. Introduction

Rowing require athletes to excel both in fitness and motion accuracy. Coaches and rowers focus their attention mostly on fitness status, embedding technique training in protocols aimed at optimizing fitness. This approach influenced and was influenced by technology: devices for monitoring physiological status were already used by trainers in the 1970s, whereas specific technologies for biomechanical evaluation of rowing gesture are still not commonly exploited. Technique is indeed evaluated mostly qualitatively by inspection of video tapes. Technologies' improvements allowed only recently to get quantitative information about rowers' motion in out-door rowing, these data were exploited to describe experts' gestures and technique features ([4]). Parallel to the development of devices for out-door rowing technique evaluation, in-door rowing simulators were developed since 1960s. These devices typically reproduce load well enough to be used for rowing training but they don't provide users with some important kinematic features (e.g the Concept2 ergometer [1], the world reference for rowers). Only recently rowing simulators providing accurate kinematics features were proposed to the market[2], whereas the most sophisticated ones have been recently developed by researchers ([7], [8]) and exploit the potential of virtual environments for training. In-door rowing systems can be used to capture and analyze rowers performance ([2],[3]). The SPRINT[3] system [7] (Fig. 1) was designed to perform in-depth analyses which aim in a first step at developing digital models of technique features, in a second one at using such models for training people. This paper shows an experiment carried out to extract rowing features from experts' performances. In this way a database useful for virtual rowers motion generation and to evaluate stroke timing and arm-forearm orientation in the finish phase (the phase in which arms pull oars, see [1] for rowing stroke detailed nomenclature) was created. Moreover, for the latter feature, a dependency of orientation on pace we did not found in the literature is presented.

Figure 1: The SPRINT system.

[1] http://www.concept2.com/
[2] e.g. Biorower: http://www.biorower.com/
[3] http://www.skills-ip.eu/row/

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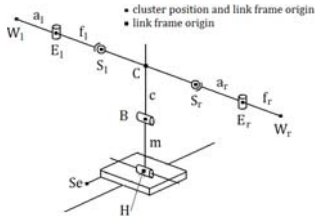

Figure 2: Scheme of the calibration pose.

2. Method

Four expert rowers (males, aged 22.2 $\pm$ 4) were asked to row on the SPRINT platform. The task consisted of performing seven technique faults and rowing correctly, it is worth noting that rowers cross their hands when sculling, and they put left one over the right regardless their handedness. Experts had to voluntary perform faults at two severity levels (minor and large) and at three paces: 18, 24 and 30 strokes/minute(spm). They had finally to row correctly at paces between 18 and 36 spm equally spaced. The protocol was therefore composed of seven faults by two levels by three paces, that is 42 blocks, plus seven blocks of correct rowing. Each block recording was manually started by the experimenter when the expert decided he was correctly accomplishing the task, the block ended by the experimenter after he had counted ten strokes, of which at least half correctly performed. Rest time was decided by the expert in order to avoid fatigue to influence mastery of technique. Experts were asked about thier fatigue status after the experiment. In addition to variables available in SPRINT, the VICON motion capture system was used for upper body motion tracking, an in-depth technique analysis indeed require detailed knowledge of back and arms motion [4]. Cluster based motion tracking was selected for its stability and reliability: rowers wore clusters of markers on their wrists, elbows, shoulders and back, one additional cluster was placed on the sliding seat. Before starting the protocol, a calibration of the system on the current expert was performed asking him to wait steady in a previously defined calibration pose. Figure 2 shows a scheme of the calibration pose along with clusters arrangement and nomenclature. All data were available in Matlab Simulink and sampled at 125 Hz. The system was completed by a Virtual Environment (VE) projected in front of the expert where, superimposed to a single sculling scenario, they could see the pace they were rowing at as a number in the middle of the screen.

3. Processing

Data processing was composed of three steps: filtering, integration with calibration data and reconstruction of kinematics. Analyzed data were wrists (W), elbows (E), shoulders (S), back (B) and seat (Se) positions with respect to a world frame whose x-axis is aligned with the seat rail and y-axis vertical. Only the upper body limbs were considered in the model: midriff, chest, arms and forearms were modeled as rigid links connected respectively by hinge, ball and hinge joints.

Filtering. Cluster data needed to be filtered because of occurred problems, in particular missing tracking or mix up of clusters. Mistaken data were removed, gaps were filled by means of spline interpolating correct data. Filtered data arrays contained the same number of samples of the original ones, the correct samples being placed in the same position as in the original arrays. Since correctness of strokes were judged by the expert himself while rowing, data were visually inspected to remove partial and mistaken strokes, in this phase were removed only strokes clearly incorrect.

3.1 Calibration

Data recorded in the calibration phase were used for correcting positions of elbows and back. Arms and forearms were assumed to be horizontal, back and chest to be vertical. The middle point C of shoulders displacement was computed and used to establish the offset of middle point H of hips positions from seat position: H was considered to be vertically aligned with H, hence obtaining horizontal displacement from Se, vertical displacement was measured for each rower. Elbows and back positions were translated to belong respectively to arm-forearm lines $\overrightarrow{SW}$ and $\overrightarrow{HC}$ (an approximation of the spine), needed offsets $\mathbf{\Delta E}_l$, $\mathbf{\Delta E}_r$ and $\mathbf{\Delta B}$ were then stored in order to translate elbows and back position for all the samples, Figure 3 shows an example of such correction in a pose different from the calibration one.

3.2 Reconstruction

Reconstruction consists of calculating positions and orientations of the links as well as joint angles from recorded data. For this purpose each link was replaced with a frame, shown in Fig. 4. Origins and axes unit vectors (called axes themselves in the following) are hence defined:

- Chest: origin in $\mathbf{C} = (\mathbf{S}_l + \mathbf{S}_r)/2$, $\mathbf{x}_c$ along the shoulder line, $\mathbf{z}_c$ vertical, $\mathbf{y}_c$ towards anterior direction.

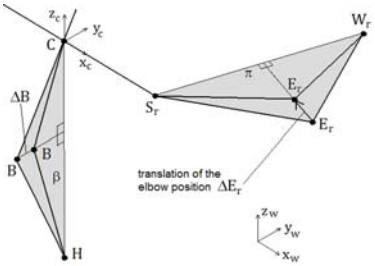

Figure 3: Correction of elbows ($\mathbf{\Delta}E_i$) and back ($\mathbf{\Delta}_B$) clusters positions.

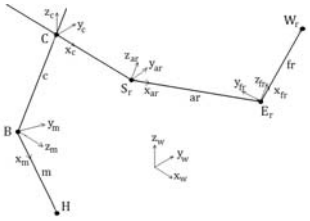

Figure 4: Representation of the link frames (left side not shown).

- Arms: origin in $\mathbf{S}_i$, $\mathbf{x}_{ai}$ along the arm, $\mathbf{y}_{ai}$ in the S-E-W planes (π_l and π_r planes), $\mathbf{z}_{ai} = \mathbf{x}_{ai} \times \mathbf{y}_{ai}$.
- Forearm: origin in $\mathbf{E} + \mathbf{\Delta E}_i$, $\mathbf{x}_{fi}$ along the forearm, $\mathbf{y}_{fi}$ in the S-E-W plane (β plane), $\mathbf{z}_{fi} = \mathbf{x}_{fi} \times \mathbf{y}_{fi}$.
- Midriff: origin in $\mathbf{B} + \mathbf{\Delta B}$, $\mathbf{x}_m$ along $\overrightarrow{BC}$, $\mathbf{y}_m$ in the C-B-H plane, $\mathbf{z}_m = \mathbf{x}_m \times \mathbf{y}_m$.

The reconstruction of body limbs started from a reference configuration (the same of calibration pose with vertical arms instead of horizontal), all body frame axes were assigned subscript 0 (e.g $\mathbf{x}_{fl0}$ for left forearm x axis) when referred to this configuration. Each current axis $\mathbf{x}_i$ can be obtained from the reference one $\mathbf{x}_{i0}$ by means of the link rotation matrix R_i defined by $\mathbf{x}_i = R_i\,\mathbf{x}_{i0}$. Rotation matrices are therefore obtained as

$$R_i = \begin{bmatrix}\mathbf{x}_i & \mathbf{y}_i & \mathbf{z}_i\end{bmatrix}\begin{bmatrix}\mathbf{x}_{i0} & \mathbf{y}_{i0} & \mathbf{z}_{i0}\end{bmatrix}^T. \qquad (1)$$

Limbs frames and rotation matrices allowed to represent all joints variables, elbows angles are given by $\theta_{ei} = \arccos\left(-\mathbf{x}_{ai}^T\mathbf{x}_{fi}\right)$; back limbs angle θ_b is defined similarly, shoulder joint rotation was defined by Euler angles for the sequence flexion θ_{sy}, abduction θ_{sx} and rotation θ_{sz}, that is, arm frame can be obtained from reference one by rotating respectively around $\mathbf{x}_{a0}$ axis, obtained $\mathbf{y}_a$, obtained $\mathbf{z}_a$. Euler angles relation with R_a components are

$$\begin{aligned}\theta_{six} &= \text{atan2}\left(\frac{R_{si}(3,2)}{\cos\theta_{siy}}, \frac{R_{si}(3,3)}{\cos\theta_{siy}}\right)\\ \theta_{siy} &= -\arcsin R(3,1)\\ \theta_{siz} &= \text{atan2}\left(\frac{R_{si}(2,1)}{\cos\theta_{siy}}, \frac{R_{si}(1,1)}{\cos\theta_{siy}}\right)\end{aligned} \qquad (2)$$

which never degenerates with rowing gesture data.

4. Technique features

In this section the map of two important ([5],[6]) technique features on the data are shown. The first is cylce phases timing the other one, related to the finish phase, is the π planes orientation with respect to gravity. They have been sought in order to get a quantitative index of skilled performance.

4.1 Timing

Timing of back swing and arms bending onset are an index of the rhythm rowers are keeping and of their ability in using their muscles in the correct sequence. Strokes were segmented at the beginning of the drive phase, when legs start pushing, oar horizontal angle ϕ was used for detecting the beginning of the stroke: the passage of $\dot{\phi}$ from negative to positive gave the stroke onset reference time. Back swing onset time T_b estimation was based on β plane orientation with respect to gravity, in particular a threshold on $\dot{\beta}$ sufficed to detect back swing. Arms bending was detected by comparing current $\overrightarrow{BC}$ length ul with the calibration one ul_0, a threshold on $ul\,/\,ul_0$ allowed to discriminate arms motion onset time T_a. Drive phase elapsed time T_d was finally marked by the passage of $\dot{\phi}$ from positive to negative. Given this framework, timing indexes were calculated as

$$t_b = T_b/T_d \quad \text{and} \quad t_a = T_a/T_d \qquad (3)$$

in order to clear linear dependency of T_i indexes on pace from the analysis. Timing indexes dependence on pace was sought mixing all expert data. Figure 6 shows results of analysis. Consistency of stroke structure was checked on drive and recovery phases times, Fig. 5 shows typical profiles of drive and recovery phases elapsed time ([6]) with the only difference that drive-recovery times ratio is smaller. Fig. 6 shows a Scatter plot of timing data along with regression curves, linearity for both was checked obtaining $R^2 = 0.29$ for back timing and $R^2 = 0.01$ for arms timing.

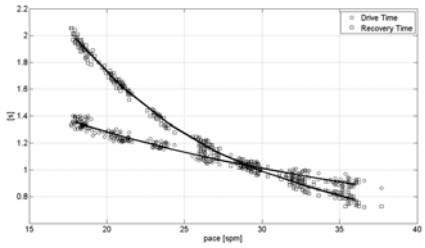

Figure 5: Drive and recovery times against pace.

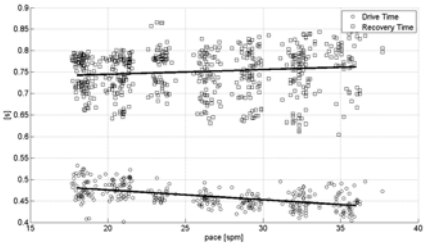

Figure 6: Plot of timing against pace for the four rowers.

4.2 Finish arm-forearms orientation

Finish phase effectiveness depends on rowers ability to keep pressure on the blade. If π_i plane is too vertical blades are likely to exit the water too early (washing out fault). Only the samples between T_a and T_d were considered to belong to the finish phase. Given n_i the unit vector perpendicular to π_i, for each sample and $v = [0\,0\,1]$ the vertical unit vector we define the finish angle $\theta_{fi} = \arccos(\mathbf{v}^T\,\mathbf{n}_i)$ which gives the orientation of π_i with respect to gravity. Figure 7 shows angles θ_{fl} for the four experts. Despite very different body sizes angles are similar for rowers 1-3, rowers 4 declared to row with elbows a little too low (that is θ_{fl} too high), it was confirmed by his coach. Data of rowers 1-3 were then tested for a dependency of θ_{fi} angles on pace. Intra-subject t-test showed the rise of θ_{fl} with pace to be statistically relevant: p-values ($\alpha = 0.01$) for 18-27, 18-36 and 27-36 comparisons are over 0.70 except for 27-36 comparison of rower 2.

5. Conclusions and future work

The present work allowed to create a database of expert rower motion. Such a database is being used to make a digital representations of technique features, to be used as a motion source for virtual rowers in the virtual environment SPRINT is provided with, and finally to synthesize rowing motion in order to develop a rowing gesture generator flexible on rowers size and training demands. This paper has also shown two examples

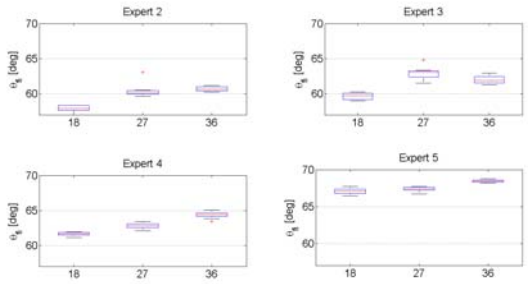

Figure 7: Finish angles θ_{fi} for the four rowers.

of how the database can be used for mapping known technique features on the training platform and how a numerical representation of gesture may lead to the discovery of unknown expert gesture features.

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