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Capturing the rower performance on the SPRINT platform

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Abstract. Capturing athletes performances with the purpose of skills training in the specific field of rowing sport is here presented, in particular The SPRINT multimodal system is introduced. This system is comprised of a mechanical reproduction of a rowing boat and of a virtual reality system with augmented feedback suited for novice and expert training. This paper details the implementation of an embedded acquisition system capable of measuring all the biomechanical data necessary for the rowing physical simulation increasing the performance with respect to the previous system.

Keywords. Multimodal system, skills training, embedded electronics

Introduction

In the last decades the number of simulators has exponentially increased. They are being used in many different fields such as industry, surgery, army, art and many others. Among them, sport is one of the last where simulators have taken place, from one hand because coaches and athletes are often skeptic about the simulator's capabilities of transferring skills; on the other hand, because the advantages brought by simulators are not as evident as in other application (e.g. flight simulators), where safety and economic issues encourage their development. When a simulator is developed for training purposes, like in sport applications, the designers has to decide which features of the real task must be replicated by the simulator to optimize training effects, under the constraints of the available resources(e.g. money, space, computational resources, etc.). Therefore, often, simulators of a specific application evolve during time, starting from a very basic device, which keeps only the main features of the real situation, and adding step by step new features as the knowledge about the real task and the available technology improve.

Training in sport is a complex argument which comprises many aspects of human behavior[1]. In particular rowing training deals both with the physiological and psychological behavior of the athlete[2]. Rowing coaches are required to address all these issues in order to make the trainee able to successfully cope with the race. Therefore, they need to gather information from the rowers performance in order to give them suitable advices. SPRINT is a multimodal rowing training system that collects in real-time these information, allowing both the coach and the athletes to monitor the ongoing performance.

After showing the rowing bases along with what is currently used for simulating outdoor rowing and for capturing rowers' performances, the paper will briefly describe the SPRINT system whereas it will focus on the embedded capturing components.

1. Professional Rowing

1.1. Rowing Bases

Rowing is an outdoor sport in which rowers propel a boat through the water. Rowers seat on a sliding seat and are fixed to the hull by means of foot-stretchers. Each rower transmits forces to the boat by means of one or two oars. Rowing with two oars per rower is called sculling, whereas rowing with one oar is called sweep rowing. The rower repeats cyclically the same sequence of movements, which is called *stroke* which, in turn, can be segmented in many phases. The most common segmentation in four phases (catch, drive, finish and recovery) is described as a first approach:

1. *Catch.* As the stroke begins, the rower is coiled forward on the sliding seat, with knees bent, arms outstretched. At the catch, the rower raises the hands to place the oar blade vertically into the water.
2. *Drive.* At the beginning of the drive, the rower keeps the coiled pose of the upper body and the legs do all the work. Then the back starts uncoiling propelling in turn the boat. In the last part of the drive arms begin their work drawing the oar blades through the water, while the back stops rotating backward when an angle of approximately 40° with respect to a vertical line has been reached.
3. *Finish.* In the end of the drive, the rower move his hands quickly towards his body, which by this time holds steady in the layback position. During the finish the oar handle is lowered, drawing the oar blade out of the water. At the same time, the rower feathers the blade that turns from vertical to horizontal.
4. *Recovery.* The oar remains out of the water as the rower begins recovery by moving his hands away from the body and past his knees. The body follows the hands and the sliding seat moves forward, with help from the feet and hips, until the knees are fully bent; the rower has already squared the blades and he is ready to raise his hands for the next catch.

The rowing stroke typically lasts between 1.2 and 4 second. In this time lapse rowers have to move practically all their limbs in a quick and coordinate manner, often when they are already fatigued. This means that some movements last only few tenths of milliseconds, therefore an accurate and timing reliable system for capturing rowers' performances is required. See [3] for further information

1.2. Rowing Simulators

Currently, the most diffused rowing simulators (Concept2 Ergometers, Morrisville, VT, USA) have a very simple kinematics: they consist of a sliding seat and a foot-stretcher similar to the boats' ones. Instead of the oars, whose motion is spherical, they provide users with a handle to be moved back and forth on a vertical plane. The handle is connected to a device that provides resistant force by means of a chain and a cable. The device that provides resistance is a fan mounted on a flywheel, during the drive phase most of the athlete's work is stored as kinetic energy in the flywheel, whereas this energy is wasted by the fan during the whole stroke. These simulators diffused because they are affordable for all rowing clubs and they allow for a quantitative evaluation of rowers. Indeed they are used by national rowing associations for ranking rowers and for selecting the country teams. These simulators give information about ongoing performance in terms of force profile, power output, strokes frequency and estimated boat speed. Since all these information are based only on fan's angular speed, boat speed estimation is rough and any information can be provided about technique correctness. Variant of this kind of simulator are the Waterrower (Warren, RI, USA) and Rowperfect[4], that aimed at improving force rendering by using the water instead of the air and by making the device slide under the rower as the hull does in outdoor rowing. Kinematic improvements are implemented in more recent simulators, such as Oartec Rower (Sidney, Australia) and Biorower (Wien, Austria), whereas the most complex simulators were developed for research purposes in the last years (e.g. ETH M3 rowing simulator [5]). SPRINT is comparable to the last as hardware complexity but it was developed for training purposes as it is presented in [6] and briefly summarized in section 2.

1.3. Capturing rowing performance

Rowers require many skills to win elite competitions. The most important skills are high muscular power, optimal aerobic and anaerobic capacity, efficient gesture, ability to perform the correct sequence of movements, ability to manage own energy stock when rowing at high pace and under pressure, ability to coordinate with teammates. Coaches and athletes have always sought for assessing performance in order to find the way to improve it. Most of the effort have been done for the physiological skills: from seventies the strongest rowing federations and clubs started measuring oxygen consumption, lactate and heart frequency to assess rowers' aerobic skills, their capabilities of carrying out effort in presence of lactic acid and establish an easy way for monitoring athletes' status during demanding training tasks and races. Little attention have been paid to technical and coordination skills, that are qualitatively assessed by inspection during the performance, or by means of videotapes analysis after the training session. In both cases there are not direct measures of the rowers' performance and therefore an immediate feedback based on quantitative information. Recent devices embedded on the boat allows for an accurate assessment of outdoor rowing, they are not diffused and they are mostly used for research purposes.

SPRINT aims at training professional rowers under both physiological and technical points of view, therefore it is required to be equipped with a capturing system able to collect in a fast and reliable way both physiological and kinetic information about ongoing performance. Moreover, since training is strongly enhanced when concurrent feedback are available, capturing has to be fast enough to allow data to be captured, processed and fed back suitably for training. The following sections will briefly present SPRINT and the sensing components embedded in it.

2. The SPRINT system

The SPRINT system is composed of a mechanical platform, a sensing system, a software system and devices for providing users with feedbacks. The mechanical platform allows to row as in outdoor rowing with almost the same kinematics and an accurate force rendering. The force rendering is given by an Energy Dissipating Device EDD composed of a flywheel and a fan mounted on. The sensing system is composed of a set of encoders and strain gage-based force sensors that are embedded in SPRINT whose acquisition is the focus of this paper. Moreover, external devices such as VICON for motion capture and cosmed k4 for oxygen consumption measurement can be integrated. The software system is composed of many parts ranging from the acquisition and processing of the signals, to the modeling of the rowing task (shown in [7]) and the management of the feedback to be sent to the users. Finally, many feedback devices are available: vibrating motor equipped belts allow for providing vibrotactile feedback [8]; speaker are available for audio feedback whereas visual cues may be provided by means of an LCD screen (see Figure 1) or by putting the whole system in a cave [9]

Figure 1 The SPRINT system in a configuration with an LCD display

3. SPRINT sensing system

The electronics embedded in the system before the enhancement described in the following, is shown in[10]. It was composed of two Microchip PIC16F887 Microcontrollers per oar, they were communicating each other via SPI in a master slave configuration. The master then sent signals via USB to the PC. The main issues with that device were the low sampling frequency (60 Hz) that could be obtained to have signal with sufficient resolution, and the synchronization of signal from the two oars.

The TMS320C2000 Microcontroller of Texas Instruments was chosen to substitute the several microcontrollers that were part of the rowing system. This device outperforms the previous as calculation speed, number of I/O ports, and, for analog signals, ADC resolution. Therefore, a reduction of latencies of the several sensorial components present on the platform is expected as well as an improvement the sample frequency in order to get a better resolution of the system signals.

Figure 2 The embedded electronic board and its connection with the sensor on the platform

3.1. Variables

The variables to be captured for assessing rower's performance are the oar rotations and the exerted forces. Oar rotations are described by the angles α and φ, that determine respectively oar handle vertical and horizontal displacements. These angles are measured out by encoders Hengstler RI58-0, which has 5.000 steps per revolution. There are two ways for estimating force on the handle, both requires to measure or calculate the torque on the shaft that bears the oar. A torque sensor composed of a full Wheatstone bridge was mounted on the shaft to have a direct measure of this torque. Because of the frailty of such a sensor, the same torque is estimated by means of a model of the physics of the EDD, which needs as input of the EDD's angular speed. Therefore a further encoder was mounted on the EDD shaft to measure out its speed.

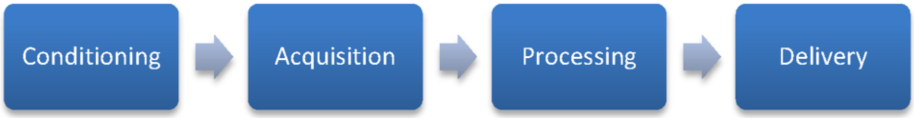
In the end a set of three encoders and a torque sensor outputs have to be captured and processed for each oar (Figure 1).Figure 2shows the placement of the device in the SPRINT system, highlighting the six signals that are captured.

3.2. Signal path

The choice of the computing element was very important in order to ensure that the electronics was low- power consumption, compact and robust, but at the same time powerful enough to handle the computing load for the signal acquisition and processing. The microprocessor has to cope with several requirements: 2 ADC/12bit for force sensor; 6 encoder inputs and 1 serial port for the communication with the host PC. In addition, 32-bit architecture and hardware floating point unit were useful to perform acquisition, processing and communication at a very high frequency.

Only two micro controller classes were found to comply with almost all the requirements: the generation of MPC5X5X from Freescale, and the control DSP F28335 from Texas Instrument. The latter was chosen for the side advantages offered by the Delfino™ control stick which implements in a single low cost module additional features such as: JTAG interface port for debug and programming, the integration with Matlab/Simulink development environment, on-board low-pass filters for ADC inputs, USB-to-Serial channels for programming and debug, and finally high operational frequency. In particular, the evaluation board integrates a TMS320F28335 running at 150MHz with a 32bits floating point unit, a fast and accurate PWM control, an integrated encoder acquisition unit and 68/512Kbyte RAM/Flash memory. Detailed specifications can be found online at Texas Instruments website.

Such a DPS allows to acquire a measure more accurately than with the previous hardware. The signal measure is composed by the following four stages:



3.2.1. Signal Conditioning

The encoder signals are TTL level (0 to 5V) with an high logical level of 5V, while the DPS works with a maximum high logical levels of 3.3V. For this reason, the logical levels must be conditioned before delivering to the DPS. The cheapest solution consists in a voltage divider even if it brings power dissipation. The final design adopts a voltage conversion stage composed by the Texas SN74CB3T3245 8-Bit Fet Bus Switch.

Torque sensors are based on strain gauges. A full Wheatstone bridge configuration was chosen because of self compensation for bending and temperature deformation. Moreover it provides a 4 times amplification of the signal. Since the force sensor signals are always comprised between 0 and 3,3V; the force signals can be connected directly to the DPS inputs avoiding the voltage conversion phase.

3.2.2. Signal Acquisition

The encoder acquisition have been done by interrupt. The TMS320C2000 Microcontroller Target of Texas Instruments has two enhancedQuadrature Encoder Pulse (eQEP) modules, while we need to acquire 6 encoder units. The eQEP modules were used to get the position count of the EDD, while the reaming encoders are read by external interrupt which drive the suitable algorithm for 4X encoders reading. According to data captured on the platform in an all-out exercise by expert rowers the maximum speed that the EDD could reach is 160 rad/s, that, according to the encoder resolution, gives a sampling frequency f_c = 260kHz. Arbitrarily the frequency work of the microcontroller and the eQEP modules was set as 4kHz.

Concerning the force sensor, since the strain gauges provide analog signals, the ADC module has been used to quantify the amount of force. The cell gains and the computing unit have been calibrated to achieve 0.05 Newton accuracy on a full scale of 800 Newton.
The sample frequency of the lecture in the ADC is 4kHz.

3.2.3. Signal processing

When an external interruption is posted, the microcontroller does a specific routine for a determinate encoder in order to increase or decrease the count of the position. To make the calculation of the speed in the EDD the registered count of the encoders was taken at fixed sample time every 1ms and multiplied by a factor in order to get the speed in radians per seconds.

The speed encoders have 2.500 counts per revolution, but since the 4x resolution technique is used, the total count per revolution increases to 10.000 counts, which deliver an angle accuracy of 0,036º per count. Now, assuming that the EDD is moving at 1 rev/s, in 1 second the encoder will count 10.000 in one direction. So, if the system takes a sample every 1ms means that if the encoder counts 10 the real speed will be 1 rev/s.

Finally, the speed factor needed in order to obtain the speed is

$$k_s = \frac{\pi \, eQEPcount}{10} \tag{1}$$

where *eQEPcount* is reset every interrupt.

3.2.4. Signal delivery

This is the final phase of the processes in the microcontroller. The communication between the microcontroller and the PC is made by an emulated serial connection. The specification of the serial connection and the total number of data bytes to be transmitted make the transmission frequency to be upper limited to 400Hz. Therefore the SCI module has been configured to work with a sample time of 0.0025 s. (400 Hz).

3.3. Results

In the following, some examples of data acquired on the SPRINT platform before and after the implementation of the new capturing system are shown. Figure 3 shows oar angles, EDD speed and captured forces before and after the implementation of the new electronics.

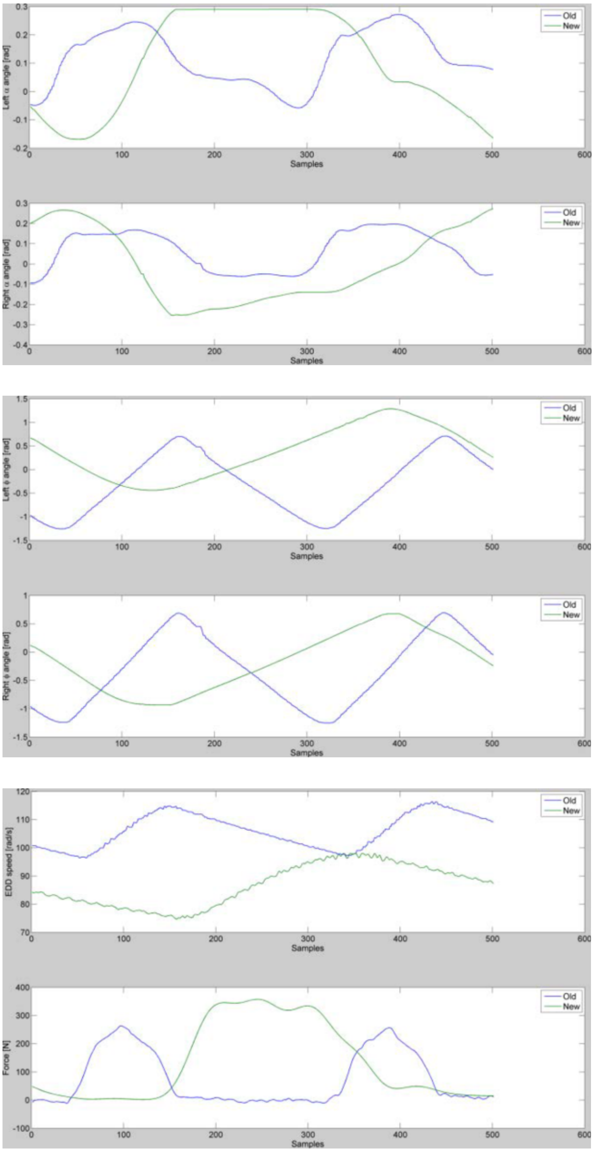


Figure 3 Oar angles, EDD speed and captured forces comparison between previous and current electronic acquisition system., time series were captured at the same stroke rate

It is possible to note that new data are sampled at roughly twice frequency with respect to old ones without loss of resolution. The improvement of the capturing is instead also in terms of resolution and communication smoothness, as shown in Figure 4.

These improvements allowed for a better simulation of the task and a better trainee's evaluation. Thanks to the higher frequency and resolution it has been possible to run the simulation of rowing and the performance evaluation at 125 Hz instead of the previous 60 Hz. It allowed for training timing of the drive phase, in which trainees were taught the correct body limbs motion onsets timing in order to optimize performance [11]. Moreover, it allowed to provide trainees with feedback at a higher frequency. Although it was not necessary for the visual feedback, for which 60Hz was enough, it has been crucial for training scenarios involving vibrotactile feedback, that is often provided for refining performance[11],[12] and hence requires to be provided with minimal latency.

Improvements in resolution (in addition to frequency one), allowed to reduce latency and improve the estimation of the signal derivatives. Since oar angles and fan speed are the fundamental information for the simulation of the rowing physics, they are required to be derived two times. Therefore, with previous electronics a strong filtering of the signals was necessary, thus increasing latency in force and boat motion estimation.

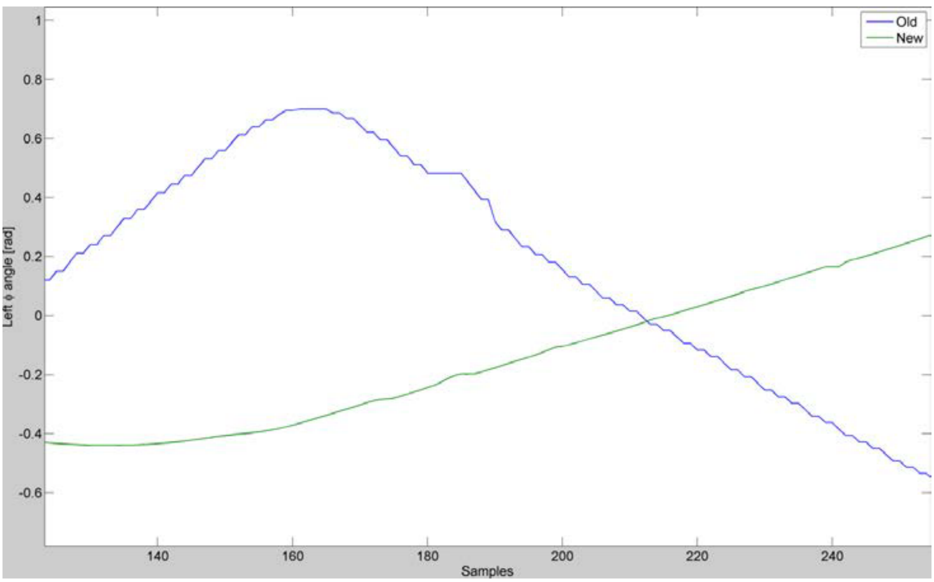


Figure 4 Closer look at resolution improvement with the new embedded electronics

4. Conclusion

This paper showed the electronics improvements of the SPRINT system. These sampling frequency and resolution improvements were and are crucial for the biomechanical analysis of the rowing gesture. They indeed allows for a fast and accurate real-time evaluation of the gesture that is the basis for providing trainees with proper feedbacks. The experiment reported in [11] shows that the obtained improvements effectively contributed to move from overall technique training to training for technique optimization.

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