Robust equipment design for a real-time coaching feedback support in watersports

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***Abstract*—In watersports, the use of on-site technical equipment for coaching support is not very common. Coaches most frequently use only a stop-watch. Wearable sensors attached to the athlete or installed into and onto sport equipment offer valuable supplemental information to coach during the practice. A technical system providing real-time feedback can make coaching more efficient. The paper presents results of our field tests in swimming, canoeing and kayaking. All listed watersport disciplines have many very similar parameters important to coaches, such as stroke frequency, stroke duration, stroke symmetry, and** others**. We focus on the definition of demands for a measurement system that would best fit watersport professionals. Our final goal is the development of a real-time feedback system consisting of waterproof wireless devices with multiple sensors supported by user friendly application. Sport professionals should be able to operate the system without constant presence of trained and experienced technical personnel (engineers).**

***Index Terms*—wearable sensors, smart sport equipment, feedback system, watersports.**

I. Introduction

Modern competitive sport is ever more relying on technology for achieving better results and competitive advantage over opponents. For that purpose the use of sensing, communication, and computing technology in a synergetic way, known as ubiquitous computing, is utilized [1]. One important constraint in technology use in sports is that it should not obstruct or distract athletes during the performed action. Real-time performance monitoring and feedback systems are particularly useful in coaching and training systems [2].

In watersports the great majority of coaches are still using only direct visual information and relatively simple stopwatch. Wearable sensors attached to the athlete or installed into or onto the sport equipment can offer valuable supplemental information to coach during the practice or after it. The main goal of our research is finding a simple and robust, but sufficient sensors setup that would provide enough information about key performance indicators in swimming, kayaking, and canoeing. Stroke periods and sport and activity specific signal peak values are listed as the key performance indicators in many watersports. Swimming is characterized by a sequence of coordinated actions of the trunk and limbs, in a repeated, synchronous pattern [3]. We can expect that at ideally performed free swimming, with perfect synchronous and periodic motion, all body attached sensor signals should be periodic. In practice this signals are cyclic with small differences in period length and period signal shape. The variation of stroke period can help coaches to grade the swimming action consistency. Similar specifics in motion signals can be found in other somehow familiar watersports, for example in rowing [6], kayaking [7], and canoeing [8].

I. Methodology and Experiment Setup

The most important parameters and tasks for free swimming analysis are found to be stroke phase analysis, stroke type identification, lap time, swim distance, stroke count and rate period, swimming velocity, kick count and kick rate. Various other parameters are important in analysis of starts and turns. Our research work focuses on the acquisition of as many key performance indicators as possible by using a simple and robust measurement system that can be adopted by coaches without any need for specialized technical support.

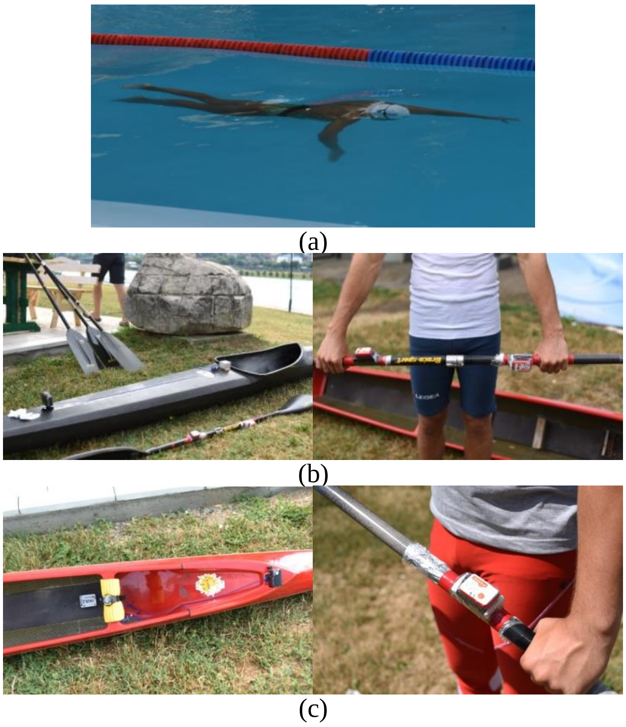

Figure 1. Placement of sensor for different water sports. (a) Swimming: the movement of the body is detected by a sensor in the belt strapped to the lower back (b). Kayaking: sensors are attached to the top of the kayak and to the paddle. (c) Canoeing: sensors are attached to the bottom of the canoe and to the paddle.

(a) (b)

Figure 2. Athletes are monitored by a GoPro camera from different view angles: (a) kayaking is monitored from the rear; (b) canoeing is monitored from the front.

In our experiments and trials we used several IMU devices with integrated 3D accelerometer and 3D gyroscope. We used different number of IMU devices, according to the needs of each sport. Figure 1 shows the positions of sensors for different water sports. In swimming we used only one IMU attached to the belt strapped to the lower back of the swimmer. In kayaking and canoeing we used several IMU devices attached to the athlete's body and sport equipment (paddle, canoe or kayak). Kayaking and canoeing actions were monitored by a waterproof camera, as seen in Figure 2.

II. Results

Swimming test consist of a continuous record of 12 laps along a 50 m swimming pool with intermediate interruptions for resting and preparation for the following lap. A sequence of twelve single lap trails represents swimming in four different stroke styles with three levels of speed: starting with slow-speed butterfly style lap, medium speed butterfly style lap and finishing with full-speed front crawl style lap. A single IMU device, attached to the back of the spine, captures enough information for accurate swimming style recognition. Other researchers mostly used only accelerometers with various algorithms to detect the swimming stroke style [3]-[5]. Our method is different and is based on the observation of three sensor signals: acceleration in anterior-posterior axis and gyroscope signals in swimming direction and mediolateral direction axis.

Stroke periods and rotation peak values serve as feedback information to the coach. We confirmed that a single 6DoF sensor unit can give us sufficient information for an accurate stroke counting and stroke rate measurements. Figure 3 shows the rotation angle signal around the longitudinal body axis for backstroke and front crawl swimming style. Basic data analysis of these signals offers valuable information about the swimming rhythm. Local maxima and local minima signal points are needed to calculate the basic features: stroke periods and body rotation angles. Figure 4 summarizes the roll body rotation angle peaks for backstroke and front crawl swimming style with three different swimming intensity levels. Stroke periods for the same swimming trials are shown in Figure 5.

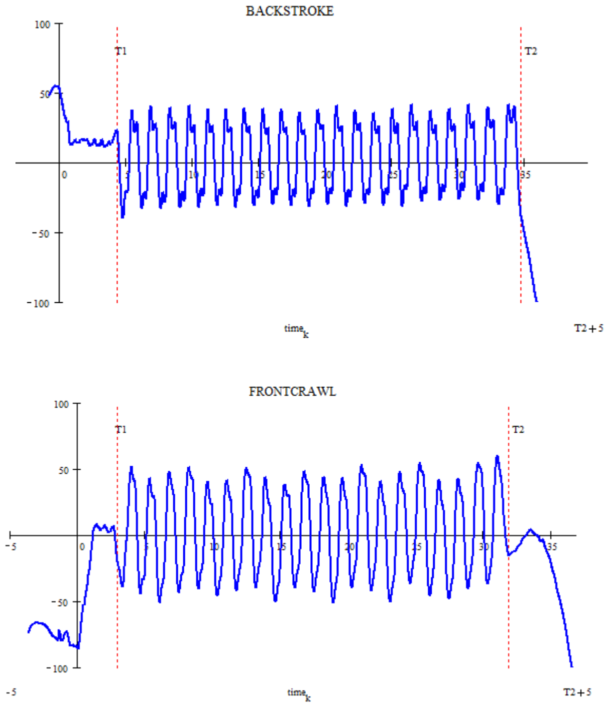

Figure 3. Rotation angle around the longitudinal rotation axis (roll angle) for backstroke and front crawl swimming style.

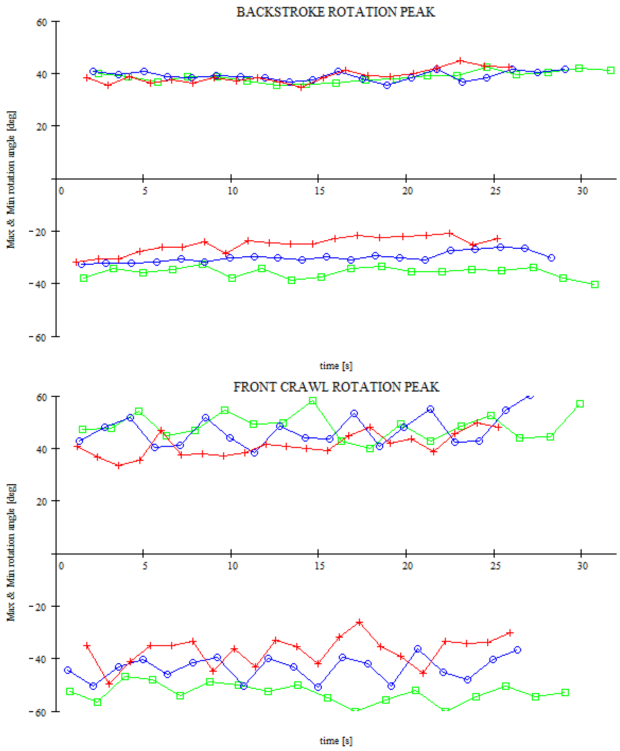

Figure 4. Peak values in rotation angle around the longitudinal swimming axis (roll) in backstroke and front crawl with different swimming intensity levels. Color codes of swimming intensity: green=low, blue=medium, red=high.

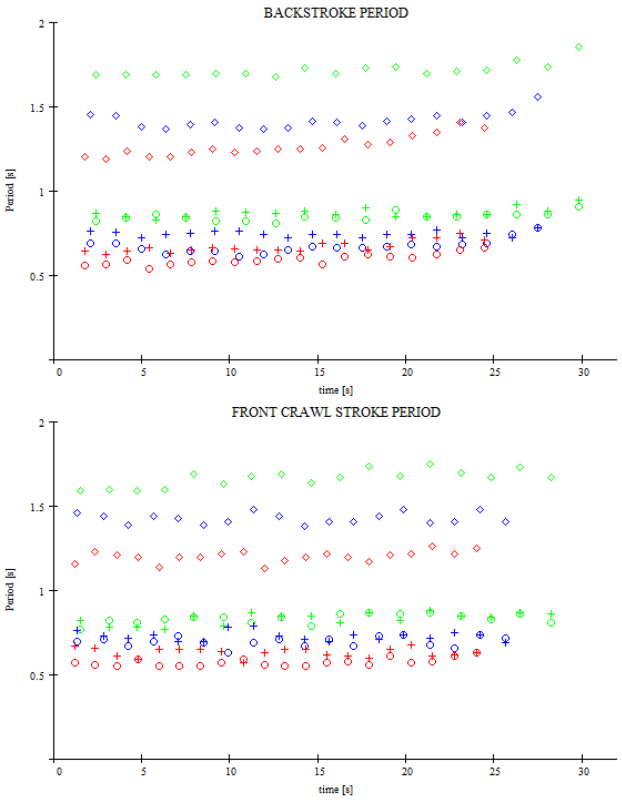

Figure 5. Stroke periods are extracted from rotation angle data (roll). Left-handed stroke periods, right-handed stroke periods, and double stroke periods are measured for different swimming intensity levels. Color codes of swimming intensity: green=low, blue=medium, red=high.

Symmetry in swimming motion in backstroke and front crawl can be acquired from the data in Fig 4. Spatial symmetry parameter is related to the rotation angle peak ratio. Asymmetry in rotation angle magnitude is related to the difference in power used during the left-hand and the right-hand stroke and also to the motor control of the swimmer. The symmetry ratio of angle peaks in both directions is calculated for backstroke and front crawl. The average lap results are shown in the tenth column of Table 1. The temporal symmetry parameter in backstroke and front crawl can be evaluated from the ratio of left handed and right-handed stroke periods from the results in Fig 5. The symmetry ratio is calculated for backstroke and front crawl. The average lap results are shown in the last column of Table 1. Stroke timing asymmetry is much higher during the high intensity swimming, where the swimmer works with full power and is less precise in motor control.

The kayak acceleration signal is shown in Fig 6 (a). The signal includes the vibrations created by the paddler movements and the noise induced by the sliding motion through water. Information about the rhythm is gained by searching the acceleration signal peak values. Analysis of the signal from Figure 6 is similar to the analysis of the swimming strokes in previous subsection. The results for stroke period and acceleration peaks are shown in Fig 7. Identical analysis was conducted on the signals of three different paddlers performing the action at three speed levels: moderate, medium, and fast. Some of the features observed from Fig 7 are: number of strokes N_{stroke}=28, stroke period T_{stroke}=0.62±0.08 s, acceleration maxima A_{max}=0.53±0.07 g_0, and acceleration minima A_{min}=0.24±0.06 g_0.

In canoeing, similarly as in kayaking, the most relevant sensor is accelerometer attached to the canoe. Figure 6 (b) depicts the signal of the medium speed trial. In comparison to the kayaking, canoeing shows stronger pulsation, with approximately twice larger acceleration and deceleration amplitude. The reason for this effect is larger force with the use of paddle with one blade. Figure 8 summarizes the analysis of stroke period and acceleration peaks of both phases of the stroke. Some of the features, together with their standard deviation, observed from Figure 8 are: number of strokes N_{stroke}=22, stroke period T_{stroke}=0.89±0.04 s, acceleration maxima A_{max}=1.11±0.17 g_0, and acceleration minima A_{min}=0.63±0.15 g_0.

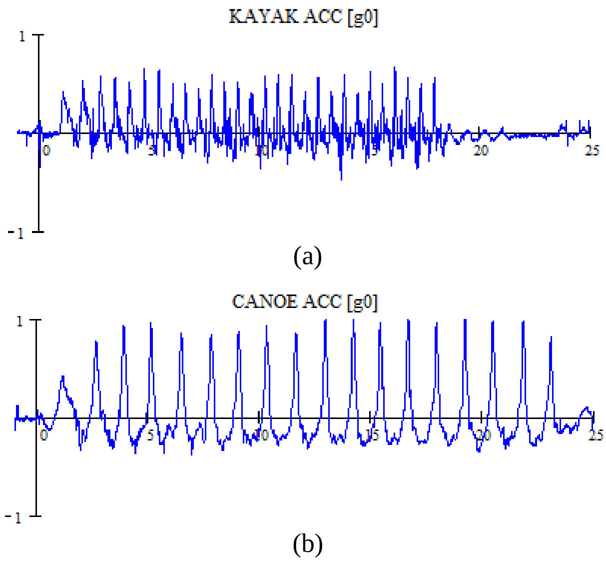

Figure 6. Boat acceleration signal in kayaking (a) and canoeing (b).

TABLE I. BASIC SWIMMING RHYTHM PARAMETERS BASED ON BODY ROTATION ANGLE AROUND THE LONGITUDINAL AXIS

Swimming Style	Speed	FS time T_1 [s]	Lap time T_2 [s]	Stroke Count	Stroke Period (Mean) [s]	Stroke Period (StDev) [s]	Rotation Angle P2p (Mean) [s]	Rotation Angle P2p (StDev) [s]	Rotation Angle symmetry	Stroke Period symmetry
Backstroke	Slow	4.82	38.56	38	1.72	0.04	74.5	3.1	1.09	0.97
	Medium	4.39	34.82	42	1.42	0.04	69.1	3.1	1.32	0.90
	Fast	4.61	33.23	43	1.27	0.06	64.0	3.0	1.59	0.89
Front crawl	Slow	3.06	34.75	38	1.67	0.06	101.6	4.8	0.93	1.01
	Medium	2.99	31.91	40	1.43	0.03	90.5	4.9	1.11	0.96
	Fast	2.58	29.98	45	1.20	0.03	78.1	6.3	1.64	0.91

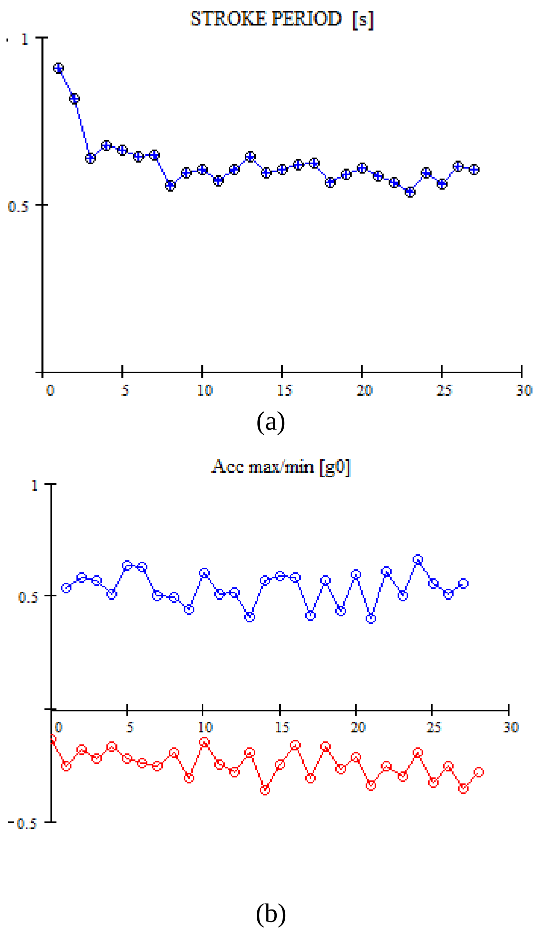

Figure 7. Features extracted from the kayak acceleration signal: (a) stroke period, (b) kayak acceleration/deceleration peaks.

In swimming we can identify features such as number of strokes, stroke periods and their variation, underwater swimming phase duration, and others. For a complete automatic analysis with timing information we should add the sensors for the wall strike detection. It is also relatively straightforward to adapt the system for the trials with a number of consecutive laps with turn detection. With the implementation of the above ideas it will be feasible to design the application that will include all the relevant information for the coach. That will allow the coach to concentrate more on other qualitative aspects of training and less on the routine quantitative measurements. Similar observations are true for kayaking and canoeing.

III. Conclusion

Our initial research and experiments in watersports confirmed the possibilities of developing of a simple, robust, and relatively inexpensive real-time technical monitoring and feedback system for supporting the coaching in swimming. A single 6DoF inertial sensor device gives enough information for stroke style detection, stroke count, and stroke rate measurements in swimming. We have also found out that various watersports share some similar key performance parameters for grading the athlete's activity. We are convinced that we can use similar signal and data analysis algorithms and methods for the application developing in several different watersports.

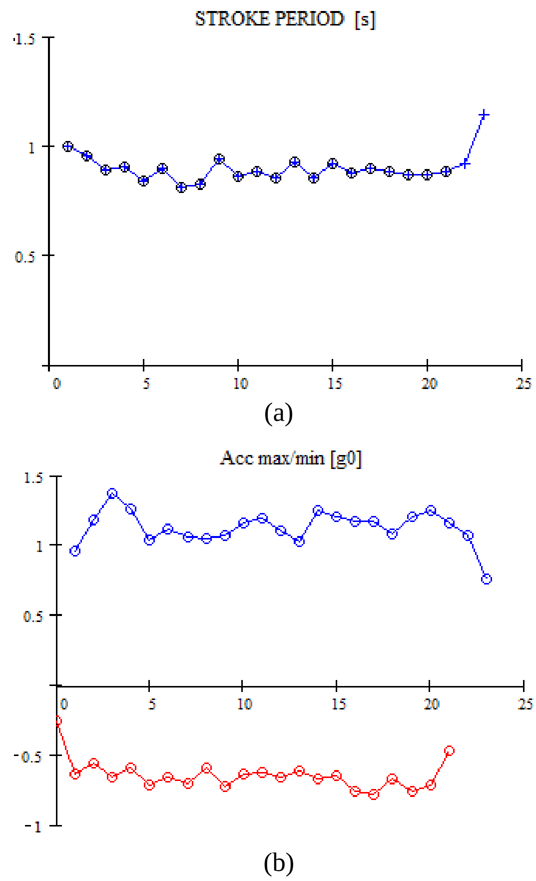

Figure 8. Features extracted from the canoe acceleration signal: (a) stroke period, (b) kayak acceleration/deceleration peaks.

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