Swimming Performance with Wearable Inertial Sensors

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CSEM further expanded its physical activity profiling toolbox for smartwatches and fitness-bands by incorporating swimming analysis. The novel algorithm is capable of computing lap count, stroke count, time in lap, total swimming time, pace/speed per lap, total swam distance, and swimming efficiency (SWOLF). In addition, several swimming styles are automatically detected. The presented algorithm has been licensed to ICON Health & Fitness Inc. for their line of wearables under the brand iFit.

Swimming is considered one of the most complete physical activity, working most of body's muscles in a variety of ways and without major impacts. Its benefits are numerous and can be practiced by people across a broad range of ages and abilities (*e.g.*, beginners, athlete, infant, elderly, over-weighted, injured, pregnant women). Like other sport activities, a precise real-time monitoring during the activity is of paramount importance to improve style and performance. However, swimming research has maturated slowly due to difficulties caused by the use of new technologies into water

CSEM extended its previously-published activity profiling algorithm [1] with results that provide swimming detection, style classification, lap and stroke count as well as SWOLF using a 3D accelerometer mounted on a wrist. This device is intended for sport and wellness applications, thus the accuracy of estimations is of importance regardless of the physical condition and training of the person.

Figure 1: Wrist device developed at CSEM for the monitoring of acceleration-related parameters.

A smart bracelet integrating a three-axial accelerometer and enough memory for 12 hours of continuous raw data recording was developed at CSEM and used to acquire raw acceleration signals at 25 Hz. The device, as shown in Figure 1, includes an LCD to display in real-time the parameters estimated with the embedded code and data-logging capabilities for offline analysis. The bracelet housing has a protection index of IP68 (6: Totally protected against dust 8: Protected against long periods of immersion under pressure). The device is capable of estimating fitness-related parameters real-time (*e.g.*, activity classes, step count, and energy expenditure among others). Raw accelerometer data and estimated parameters can be stored and can be downloaded into a PC for further analysis.

During development, a total amount of 69 recordings were collected. The total number of laps adds up to 2679 combining all swimming styles. An ensemble of 5 randomly-selected recordings were used to train the different sections of the algorithm during its development. For the scientific validation, references for swimming style and lap count have been notified by volunteers through a standardized form, while stroke count has been determined by manual annotations of the acceleration signals. The protocol conceived to validate the system and evaluate the accuracy of the algorithm was designed regardless of the swimming expertise of the user. Therefore, several elements of the protocol were decided by the user according to their capabilities. The user was free to choose between open turns, tumble turns, backwards flips, or stopping to catch the breath as well as the size of the swimming pool (50 m or 25 m).

The algorithm was implemented in fixed point for a low-power system. In particular, a system-on-chip was used with a microprocessor ARM® Cortex®-M0 with an average consumption of 13.9 µA and a memory footprint of 412 bytes of RAM and 2780 bytes of flash.

Table 1 shows the performance results of the lap. False positives make reference to the missed laps, and false negatives are usually related to two laps joined into a single one. Preliminary results on style classification and stroke count have been previously published [2].

Table 1: Performance results of the lap detector.

	Lap count		
	Backstroke	Breaststroke	Front crawl
True positives	193	618	1854
False positives	0	4	5
False negatives	1	3	7
Precision	100.0%	99.36%	99.73%
Sensitivity	99.48%	99.52%	99.62%

Based on the presented and published results, the proposed model for swim analysis offers a high accuracy for swimming activities in the three main swimming styles. More precisely, we achieve precision and sensitivity values that are greater than 99% for lap detection and greater than 92% for style classification. Moreover, the stroke counter relative error is below 1.2% in the worst case. In view of these promising results, the suggested novel wrist sensor paves the way towards a new generation of affordable, comfortable, easy-to-use swimming monitor devices.

• ICON Health & Fitness Inc

[1] R. Delgado-Gonzalo, *et al.*, "Physical Activity Profiling: Activity-specific Step Counting and Energy Expenditure Models Using 3D Wrist Acceleration", in Proc. EMBC '15, Milano, Italy, 2015.

[2] R. Delgado-Gonzalo, *et al.*, "Real-time Monitoring of Swimming Performance", in Proc. IEEE EMBC'16, Orlando, USA, 2016.