Pulsemon – Wrist Sensor to Measure Speed, Distance, and Heart-Rate of Runners

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Endurance athletes use wearable and minimally obtrusive monitoring devices to evaluate their physical conditions and their progresses, as well as to construct an optimal training program. Heart rate is probably the most popular indicator of exercise intensity and nowadays can be estimated with a large variety of devices available on the market. However, heart rate depends on an athlete's physical condition, mental status and on environmental parameters, thus it is not the most representative indicator of exercise intensity. Speed or pace (time/distance) provides instantaneous feedback of exercise intensity for runners and is robust to all said factors.

There is a wide range of GPS-based products on the market. The global positioning system (GPS) involves a dozen satellites that communicate with the device to measure its absolute position in real-time. Speed, pace, and traveled distance are then estimated tracking the device displacements. These devices do not need calibration for their absolute positioning and are becoming smaller, lighter and sleeker, but they have a poor autonomy, are expensive, and accuracy decreases when a clear view of the sky is not available, up to the point where they lose the signal.

Another family of speed and pace monitoring devices for runners is characterized by the use of accelerometers. An accelerometer-based device consists of a motion sensor that senses each strike of the run and extracts from that the information to estimate speed and pace. These devices are not as accurate as GPS. Also, accuracy is partially dependent on individual calibration but they are cheap, easy-to-use and avoid waiting time due to cold-start. The biggest advantage of this approach is that accelerometers are small, cheap, instantaneously available, and their power consumption is very low (typically 40µA @100 Hz). Commercial approaches locate the sensor either in shoes (foot-pod) or in chest-belts.

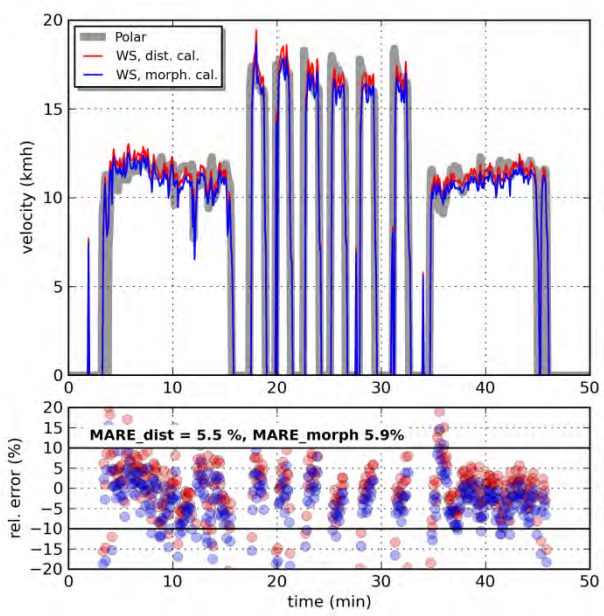

Figure 1: Typical result of running speed estimation using different calibration schemes and their respective error results.

CSEM has developed a watch-like device integrating a 3D accelerometer for robust running speed and pace estimations and a photo-plethysmographic (PPG) sensor to estimate heart rate (HR). Inertial data processing consists of applying a leg-and-arm dynamic motion model to 3D accelerometer signals [1]. The motion model can be either calibrated on fixed distance or a constant speed period. Additionally, the system can be parameterized with the subject's morphological data (height, weight, leg length) without requiring a specific calibration.

From the estimated speed, an *a priori* HR model is evaluated in order to improve the algorithm processing PPG signals for HR estimation. This processing strategy increases the robustness of the estimation when the quality of the optical signal is very poor. Each time the PPG signals provide a reliable estimation of HR, the *a priori* model based on the inertial measurements is adapted to user specificities (relation between HR and running speed).

Preliminary results are based on seven different subjects performing an outdoor training session on a hard surface with flat profile. Training sessions include running speeds between 8 and 17 km/h. Volunteers span across different weight (55-90 kg) and height (165-195 cm). Figure 1depicts a typical result of a training session. The upper part depicts the result for the speed estimation by using the two calibration approaches (distance and morphological) with respect to the reference foot-pod system (Polar RS-800). The lower part of Figure 1 presents the relative error as well as the mean absolute relative error (MARE) for the two calibration schemes. The following table summarizes the performances of the proposed approach. The distance calibration exhibits a slight advantage, but requires a specific calibration session.

Calibration	Mean (km/h)	Std (km/h)	MARE (%)
Distance	-0.1 ± 0.07	1.10 ± 0.33	4.76 ± 1.31
Morphology	-0.28 ± 0.51	1.50 ± 0.63	5.81 ± 1.19

In view of these preliminary but promising results, it appears that the suggested novel wrist sensor paves the way towards a new generation of affordable, comfortable, easy-to-use runner speed monitor devices (a patent application was filled mid 2013). The wrist-located device shows performances comparable to calibrated foot devices and an extension of the dynamic motion model is currently being developed for walking scenarios. The influence of the surface as well as those of the declivity is also being investigated.

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[1] R. Blickhan, "The spring-mass model for running and hopping", Journal of biomechanics 22.11 (1989): 1217-1227