Highly Accurate Step Detection from a Wrist-worn 3D Accelerometer

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Step counting is the most used fitness and healthy mobility metric. Specific daily step recommendations have been provided by health organizations ever since the benefits of accumulating daily walks on overall health have been demonstrated. With smartwatches becoming ever so popular, many wrist-based algorithms have been developed to count and report steps. However, an objective validation of such algorithms is lacking. In this work, several algorithms were compared in different use-case scenarios for step counting, revealing the excellent accuracy of CSEM's approach.

Mobility is one of the main indicators of quality of life. As people moved to more sedentary lifestyles in recent centuries, it is crucial to remain active to retain the health benefits of movement and exercise. The WHO recommends that adults perform at least 10 000 steps per day, and this figure has been highlighted in scientific studies [1].

With the advent of MEMS, early pedometers were replaced by 3D accelerometers, whose signals vary with motion, enabling them to count steps. The body location at which these sensors are placed is important: for instance, the foot location has a clear advantage as steps inherently require foot motion, whereas the wrist is the location with most adoption, owing to the ubiquity of smartwatches. The main challenge at the wrist is to detect steps correctly while rejecting non-stepping movements, to reach a high accuracy and avoid over or under counting.

Different techniques have been used in the literature, including machine learning, peak detection, pattern matching, and frequency detection. CSEM's proprietary algorithm relies on a biomechanical model with a frequency calculation method that allows it to be robust to walking and running step detection [2].

This algorithm was put to the test in a study conducted by CSEM's partner, ActiGraph. A total of 17 healthy subjects performed 6 different tests, including 1-minute walking tests at slow, comfortable, and fast speeds, with two additional tests at comfortable speed: hand in pocket or holding a phone in the hand on which wrist sensor is worn. A 6-minute walking test was also performed. All users wore a GT9X and a CentrePoint Insight Watch (CPIW), two devices from ActiGraph each containing at least a 3D accelerometer. The collected data was run through 6 different algorithms:

- Lee, *et al.* [3]: peak detection with adaptive thresholding
- ADEPT [4]: pattern matching with predefined templates
- Femiano, *et al.* [5]: autocorrelation and peak detection
- CPIW v1: random forest with statistical signal features
- CPIW v2: improvement of v1 trained on larger age range and more activities
- CSEM: instantaneous motion frequency detection and biomechanical model

The results of the different algorithms are shown in Table 1.

Table 1: Step count results (SD: standard deviation, RMSE: root mean squared error).

Algorithm	Accuracy (%) ± SD	RMSE (steps)
CSEM	96.7 ± 6.4	11.4
CPIW v2	95.3 ± 6.0	9.4
CPIW v1	95.1 ± 7.5	10.6
ADEPT	90.1 ± 10.3	17.9
Femiano, *et al.*	82.7 ± 22.2	43.1
Lee, *et al.*	59.8 ± 41.4	155.2

Compared to video reference, CSEM's algorithm had the highest accuracy (100-mean absolute percent error) at 96.66%, with CPIW v2 achieving lowest RMSE. The other algorithms exhibited lower accuracies: 90% for ADEPT down to 60% for Lee, *et al*. These results demonstrate that a motion frequency or a machine learning based approach is better suited to step detection than pattern matching or peak detection (which fared the worst). Besides, CSEM's algorithm works in a real-time fashion and is highly suitable for low-power, embedded applications.

The CSEM algorithm spans both general health and lifestyle monitoring, as well as step detection for clinical applications, and is easily adaptable to new applications since it does not need retraining. This study further demonstrates the accuracy and validity of CSEM's approach. Besides, this algorithm is part of an activity classification library that includes the analysis of walking, running, swimming, resting, and workouts, providing a complete solution for detailed activity monitoring and behavioral profiling.

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