Activity-specific Energy Expenditure Models Dedicated to Multi-modal Platforms

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CSEM developed three new methods to estimate energy expenditure (EE) based on accelerometry and heart rate (HR) monitoring. Their accuracies were evaluated together with state-of-the-art EE estimation devices of the market over a wide range of intensities in a given set of activities, ranging from sedentary to vigorous. Based on their performance, the proposed models provide a significant improvement over the state of the art. The embedded models represent an improvement for most of commercial wellness and training wearable devices.

Recently, several studies presented new approaches combining long-term wearable miniaturized sensors with activity-specific EE estimation models [1]. These approaches first classify the physical activity of the subject, and then apply an activity-specific EE model. However, the evaluation of these models is not clear or is poorly documented. Moreover, the EE model inputs vary from activity class, through subject's anthropometric parameters and subject's fitness indicators, to precise calibration values and HR. A clear overall picture of the accuracy of such EE models is therefore required.

CSEM proposes three different human activity-specific EE models. These models range from two simple models based on the subject's estimated speed and anthropometric parameters (*speed*-based model), instantaneous fitness parameters (HR-based model), and a more complex one using estimated speed, anthropometric parameters, and fitness parameters (*hybrid* model). The performances of these three models were evaluated with respect to gold standards (treadmill speed and body energy expenditure estimated from indirect calorimetry) and compared to published EE models embedded in commercial devices.

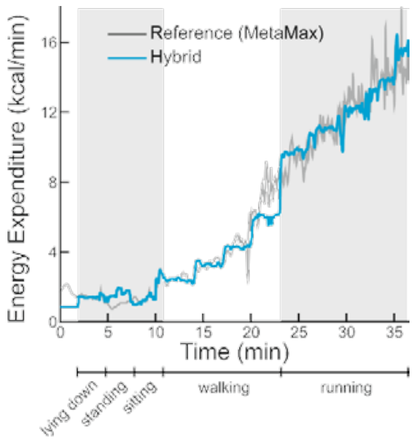

Figure 1: Evolution of estimated EE values from the hybrid *model and ground truth values of a subject over the entire protocol.*

In CSEM models, 3D accelerometer signals are used for the classification of physical activity and the estimation of walking/running speed. The resulting activity-specific episodes are used to fit an activity-specific speed model based on common anthropometric parameters and biomechanics principles. The resulting speed estimates and activity-specific episodes constitute the main inputs of the proposed EE models [2]. The *speed*-based model is estimating the EE for each activity by taking into account speed and anthropomorphic parameters of the user. The HR-based model estimates the EE on each activity category using instantaneous HR values only. These HR values are obtained by applying an R-waves detection algorithm to ECG signals. The *hybrid* model combines both models into a single expression with the addition of quality indicators. The coefficient values of the *speed*- and HR-based models were estimated by performing a leave-one-out procedure based on multi-linear regression. The performance of each model on a protocol that included a wide range of intensities in a given set of activities, ranging from sedentary to vigorous, are quantified by root-mean-squared values of 1.22±0.34 kcal/min, 1.53±0.48 kcal/min, and 1.03±0.35 kcal/min, resp. (N=8). Figure 1 shows an example of the EE evolution during the mentioned protocol. Figure 2 shows the absolute error distribution of the *hybrid* model in terms of estimated kcal/min with respect to the activity class for a specific subject.

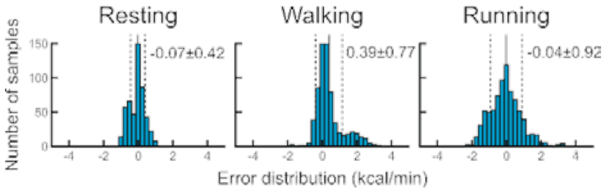

Figure 2: Error distributions of the hybrid *model at different activities for a specific subject.*

When compared to actigraphy-based devices, the *speed*-based model outperformed off-the-shelf devices. When compared to ECG-based devices, the *hybrid*-based model sustained the comparison, see Table 1.

Table 1: Performance of activity-specific EE models.

Speed-based model	Total EE relative error
Actigraph GT1M	26.8%
Fitbit	28.7%
CSEM	**5.5%**
Hybrid-based model	**Total EE relative error**
Polar S801i (incl. stride sensor)	0.5%
SenseWear Pro Armband	2.5%
CSEM	**0.7%**

CSEM results [3] indicate that if commercialized devices would include such novel models they would improve their performances in terms of EE estimation. The actual model selection should be dictated by the type of embedded sensors such as 3D accelerometers, GPS, and/or dry electrodes.

This study was possible by grants from the FP7 EU project PEGASO (FP7-ICT-2013.5.1), and the Wilsdorf Foundation.

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