PNI White Paper

SENtral-K ROM Pedometer Algorithm Performance Evaluation

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November 2014

Scope

This report describes the expected performance of the SENtral-K Step Counter ROM code algorithm. The results from this report utilized the Matlab algorithm source code that was used to generate the C-code for the SENtral-K ROM. The scope of this report does not include the process of ensuring the C-code matches the Matlab code, and thus there is an inherit assumption in this report that the 'Matlab code = the ROM c-code'. To get the performance contained in this report, the algorithm knob settings must be defined into the SENtral-K RAM.

Algorithm Description

PNI's Pedometer algorithm was designed to operate asynchronously, *i.e.,* algorithm rate *vs.* accelerometer output data rate (ODR), with 'always-on' accelerometer data being fed into the algorithm with an ODR of 30 Hz or higher. We won't have the exact power consumption of this algorithm until we make measurements on SENtral-K HW in Q1 2015. That said, we expect approximately 60 uA for the algorithm in SENtral-K with a 30 Hz accelerometer ODR with only few uA increase in power for the accelerometer ODR between 30 Hz and 100 Hz. The algorithm includes 43 different knob settings, including a few dynamic / adaptive knob settings, as well as several conditional knobs, *i.e.,* knob values if context is 'walking' vs. context is 'not walking'. While we are not going to discuss in detail our accelerometer-only pedometer algorithm, we will share that our approach applies both bio-mechanical and heuristics-based filtering on threshold crossing features extracted over a 4-deep step buffer to accurately identify false or missing steps. As a side note, the end user has the option to decide if they want to wait until the 4-deep step buffer is full, and thus live with the latency of 3 steps, or get steps real-time as they are sensed, and then have step counts that are sporadically added or subtracted based on the feature extraction filters over the 4-deep step data buffer. PNI's algorithm does not currently output step length, but we have step frequency, which the user can use in combination with leg length to relate the step count to step distance. [1]

QA Methodology Overview

PNI used 194 test vectors--including Brajdic's 'unconstrained smart phone' open source data, [2] [3] which include both slow and fast walking in each file--as well as data captured by PNI including 30+ minutes of driving data with zero steps. The total log time was 305.25 minutes with 16,726 truth steps. Simulations were run through a Matlab model, which enables 43 different algorithm knob settings to be varied. As part our deterministic methodology, we added 'whichtrigger' counters at various locations in the algorithm to enable us to quantify how often different sections of the code are processed as a function of the knob settings. All 194 test vectors were processed for each of approximately 2500 simulations. At about 5 minutes per simulation, this was approximately 200 total hours of computer processing time. The results for each simulation were output to a .csv file and the output data was analyzed to find the optimal settings. The final results were tabulated as an accompanying .xls file 'SENtral-K_ROM-Final_11-14-14'.

Quality Metrics

PNI uses several quality metrics to assess the performance of our pedometer algorithm. These include first, % accuracy, which is defined as the total steps / total truth steps; second, median error %, which is defined as the median of the sample population for the metric defined by equation (1):

$$(1) \qquad \%\ error = \frac{F_p + F_n}{T_p}$$

where F_p is false positive count, F_n is false negative count, and T_p is the total true positives count, *i.e.*, truth. The importance of using equation 1 to calculate % error is illustrated with the following example. For a test vector with 100 steps with 1 Fp and 1 Fn, the accuracy is 100% but the % error is 2%. To facilitate calculating % error, test vectors were labeled with start and stop timestamps to enable us to quantify the step count inside the time stamps and outside the time stamps, *i.e.*, false positives. Third, we also provide % of tests with Fp and Fn at or below a threshold of 0, 1, or 2 counts. Lastly, PNI uses the balanced F-measure (*i.e.*, F1 score) as an additional quality metric to assess the quality of our Pedometer algorithm. The F-measure is a weighted harmonic mean of precision and recall, where an F-measure score reaches its best value at 1 and worst at 0. The F-measure uses both the precision and recall of a test to calculate the F1 score, as shown in equation (2):

$$(2) \qquad F_1 = 2 \times \frac{precision \times recall}{precision + recall}$$

Precision is calculated as the number of correct results divided by the total number of results, as shown in equation (3):

$$(3) \qquad precision = \frac{T_p}{T_p + F_p}$$

Recall is the number of correct results divided by the number of results that should have been returned positive, as show in equation (4):

$$(4) \qquad recall = \frac{T_p}{T_p + F_n}$$

Results and Discussion:

There were 16,726 total steps inside the start and stop time stamps, and the algorithm step count result was 16,770, resulting in a step count accuracy of 100.26%. The algorithm produced 488 Fp and 87 Fn, with a resulting median error of 1.46%. The distribution of Fp and Fn are shown in Figure 1 and Figure 2. 90.2% of the test vectors had 1 Fn or less while 73.7% had 2 Fp or less. A summary table of the QA analysis results for our Pedometry algorithm is provided in Table 1 below.

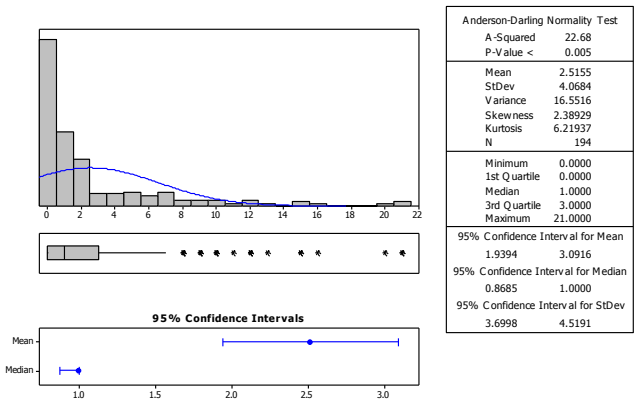

Figure 1: False Positives for 194 test vectors

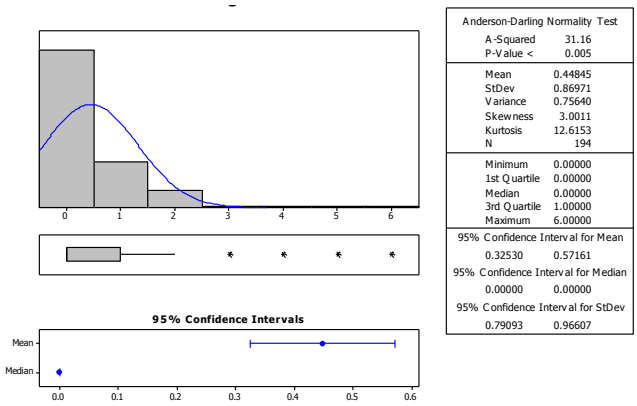

Figure 2: False Negatives for 194 test vectors

Table 1: Summary of Algorithm Results for 194 Test Vectors

Total Files	194
Total Steps	16770
Total Truth	16726
Total Fp	488
Total Fn	87
Total log time (minutes)	305.26
%Accuracy	100.26
% Median Error	1.46%
% 0 Fp	42.78%
% 0 Fn	70.10%
% 1 or less Fp	61.86%
% 1 or less Fn	90.21%
% 2 or less Fp	73.71%
% 2 or less Fn	97.94%
Mean F1 Score	98.30%
Mean Recall	99.43%
Mean Precision	97.30%
Latency	3 steps

Conclusions

PNI has completed a comprehensive analysis of our accelerometer-only SENtral-K pedometer algorithm with our standard knob settings. While the performance is quite good, there may be some users who want a slightly different user experience. For example, some users may want knobs optimized specific to athletics, such as running or lunges. Or, a user may want a reduced quantity of Fp even at the cost of increased Fn. As part of the SENtral-K product launch, PNI will provide further information on the knobs available to the user.

References

[1] Zijlstra, Wiebren. "Assessment of spatio-temporal parameters during unconstrained walking." European Journal of Applied Physiology 92, no. 1-2, 2004, pp. 39-44.

[2] Brajdic, Agata, and Robert Harle. "Walk detection and step counting on unconstrained smartphones." In Proceedings of the 2013 ACM International Joint Conference on Pervasive and ubiquitous computing, 2013, pp. 225-234.

[3] http://www.cl.cam.ac.uk/~ab818/ubicomp2013.html

Revision Control Block

Revision	Description of Change	Effective Date	Approval
01	Initial Release	11/15/2014	ATaylor