Estimating step count from a trunk mounted inertial sensor

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The purpose of this document is to explain how the Shimmer algorithm to count steps from a trunk mounted inertial sensor functions as well as to present the validation results.

1 INTRODUCTION

Step counting is an important metric for understanding the activity levels of participants in the home and community setting. With the advancement of sensor technology it is now possible to obtain wearable sensor data from people as they go about their daily life. Obtaining useful metrics from such data is important and counting steps is a fundamental metric that can be used to assess people's activity levels throughout the day, week, month and year.

The purpose of this report is to present a method of detecting step count from a trunk mounted accelerometer as well as to present the validation results of the method.

2 MATERIALS & METHODS

2.1 SUBJECTS

37 subjects, 14 female and 23 male (26 years ± 8, height 175cm ± 9, weight 72kg ± 13, BMI 23 ± 3) were recruited from the University campus and wider community through the means of posters and advertisements. Subjects were eligible to participate in this study if they were over 18 years of age and were capable of providing informed consent. Exclusion criteria included; (1) unexplained falls within the last year, (2) active medical treatment, (3) fractures, surgery or hospitalization within the last 3 months and (4) serious neurological pathology. Ethical approval was sought and obtained from the University Health Research and Ethics Committee. All subjects provided written informed consent prior to being included.

2.2 PROTOCOL

The testing protocol consisted of a roughly five minute walking loop around several floors in a building on the University campus. This walking path consisted of several doors to go through, an elevator to take down a floor and a set of stairs to walk up. These features were included in the walking trial to enhance the ecological validity of the study. Prior to the commencement of the walking protocol, each subject’s height and weight was obtained. The inertial sensor was placed at the level of the 3rd lumbar vertebra in order to closely match the lower trunk acceleration during gait; previous work in the area has utilized the same mounting location, which is considered to be near the centre of mass while walking [1], [2]. Each sensor was fixed in place with an elastic strap. A researcher followed the participants as they walked the path and told them where to go. The researcher used a hand-held counter to manually count the number of steps that the participant took during the walking trial.

2.3 IMU PROCESSING

A Shimmer 3 (Dublin, Ireland) inertial sensor was used at a sampling rate of 256Hz. Sensor firmware and configuration settings were set using Consensys v0.3.0 (Shimmer, Dublin, Ireland). The tri-axial accelerometer signals were enabled and set to ranges of +/- 4G. Data was stored on an on-board Mirco-SD card and downloaded after each test was complete. MATLAB 2014b (Natick, MA, USA) was used to replicate previously published algorithms which were designed to count steps from inertial sensor data [3]. Local vertical acceleration from the inertial sensor was band pass filtered between 0.2 Hz and 1.3 Hz; peaks were found in this signal to identify each step. Figure 1 shows an example of the filtered vertical acceleration signal, the dashed vertical lines represent where steps are found.

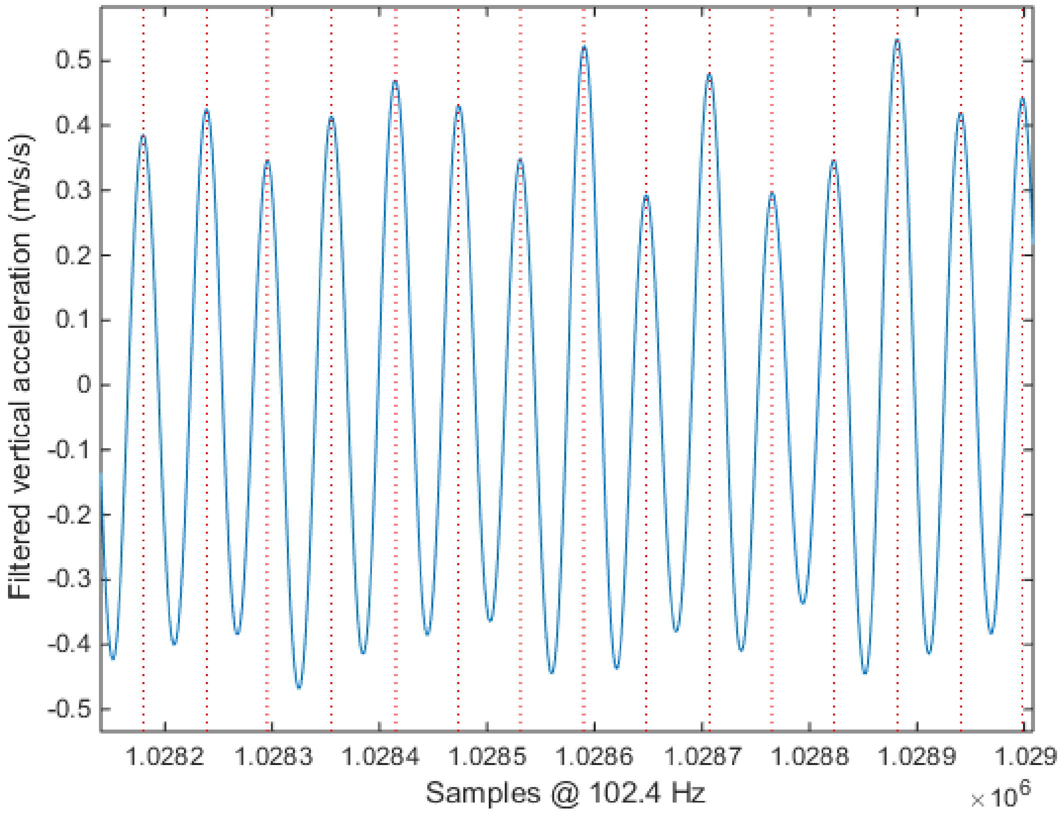

Figure 1 - Filtered vertical acceleration signal from the trunk mounted inertial sensor. Vertical dashed lines represent where steps were found.

2.4 Statistics

Statistical analysis was performed in order to determine the validity of the algorithms estimation of number of steps. From each walking trial, two step counts were obtained; one from the gold standard manual step counter and another from the Shimmer step count algorithm being applied to data from the trunk mounted inertial sensor.

A Bland-Altman style analysis was conducted in order to determine the levels of agreement between the gold standard gait parameters as determined by the force platform and those derived from the gait detection algorithms [4]. Mean difference (MD) was calculated. The 95% confidence interval (95% CI) was calculated to demonstrate the precision of the estimated limits of agreement, using the formula

$$CI = X \pm (1.96 * s) \qquad (1)$$

where X is the average of the mean differences and s is the standard deviation of the mean differences. The confidence interval width was then determined in order to obtain an understanding of the range of accuracy in which 95% of results would be expected to fall. Additionally, Pearson correlation coefficient was calculated in order to determine the level of correlation between the optical system and the inertial stride time measures.

3 Results

A summary of the validation metrics are shown in Table 1.

Validation metric	**Value**
Pearson product correlation	0.961
Mean difference	-1.081
Standard deviation difference	4.63
95% Confidence interval upper limit	8.00
95% Confidence interval lower limit	-10.16
Confidence interval width	18.16

Table 1 - Validation metrics comparing step count from the Shimmer algorithm applied to the inertial sensor data compared to the gold standard manual step count.

Figure 2 shows a graph in which the step count from the Shimmer algorithm applied to the inertial sensor data is compared to the manual step count for each participant. The dashed line has a slope of 1.0 and represents where each data point would lie if both systems were in perfect agreement.

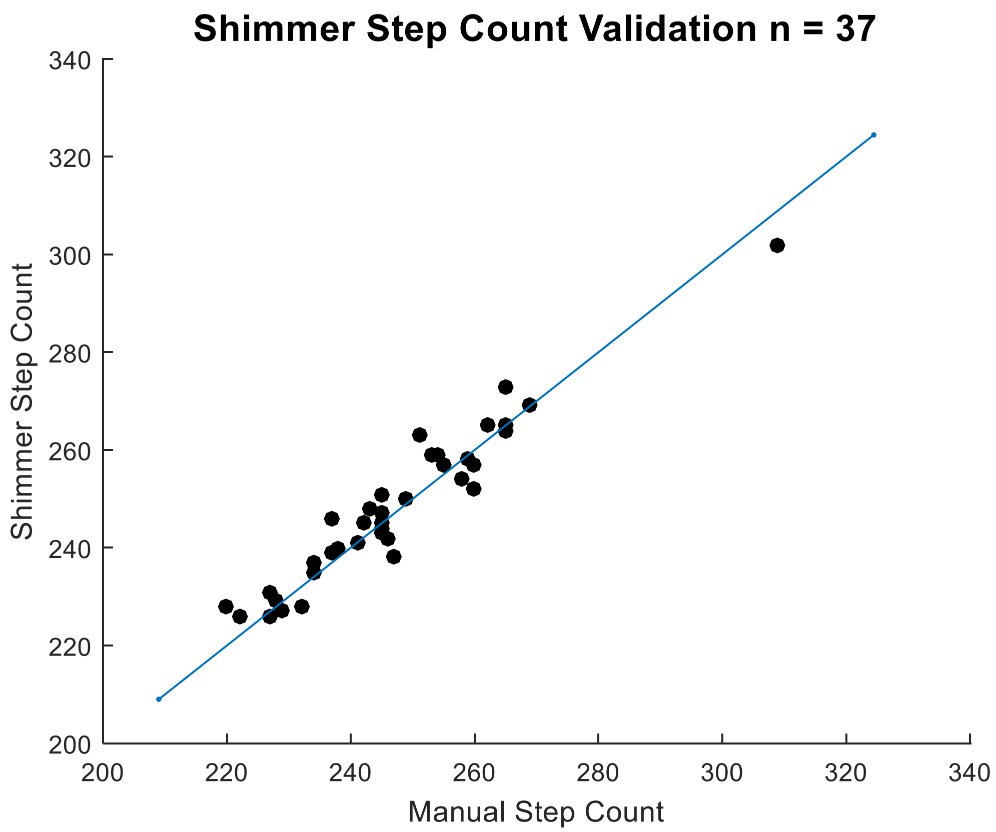

Figure 2 - Step count from the inertial sensor plotted against manual step count for each participant. The dashed line has a slope of 1.0 and represents where each point would fall if both systems were in perfect agreement.

Figure 3 shows a graph where the average of both step counts are graphed against the difference between the two systems. The upper and lower horizontal lines represent the upper and lower 95% confidence intervals. The dashed horizontal line represents the mean difference.

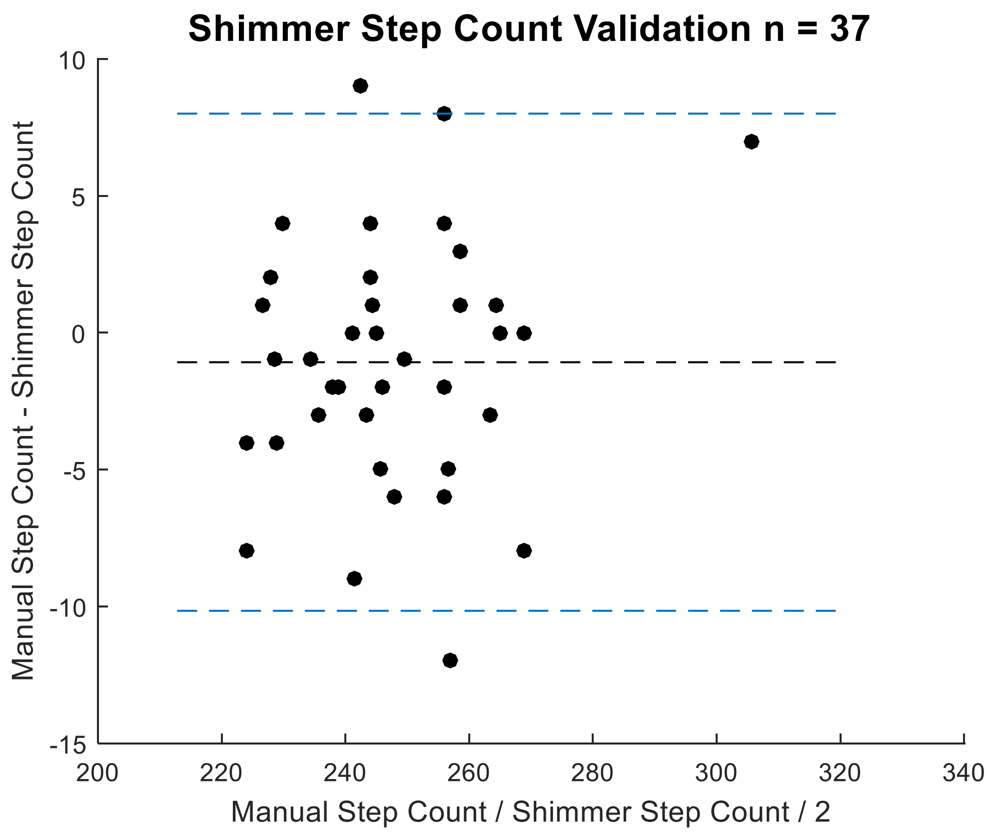

Figure 3 - Difference between step count from both systems plotted against the average of both systems. The dashed black line represents the mean difference and the dashed blue lines represent the 95% confidence intervals.

4 Discussion & Conclusion

The purpose of this study was to assess the validity of a step counter that is based on using acceleration data from a trunk mounted inertial sensor. Results indicate that the algorithm to count steps performs up to a high standard. 95% of the time, there is confidence that the number of steps counted lies within plus or minus 18 steps. This translates to an error of roughly 6%.

There was a slight negative bias to the step count from the algorithm when compared to the manually annotated step count (mean difference = -1.081 steps). The Pearson Product Correlation Coefficient showed high levels of correlation (r = 0.961), which falls within the 0.90 – 1.0 excellent level of positive correlation range [5].

The data-set used in this validation included a significant amount of *real world* walking conditions; participants were walking through door-ways, upstairs as well as in and out of an elevator. Considering that these algorithms are designed to work in real world settings, it was important to include such walking events in the protocol.

In conclusion, it can be stated that the Shimmer algorithm to count steps from a trunk mounted inertial sensor can provide an accurate step count in real world conditions.

5 References

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