Re-engineering smart shoes to add measuring features: useless or useful?

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Summary

A prototype of smart shoes, already effectively used to detect gait phases, might usefully broaden its measuring features by exploiting its three force sensors to infer on the foot pressure mapping. This study represented the first step of the thorough assessment, and investigated whether the shoes are suitable to deliver reliable pressure measurements and, in case, whether some re-engineering is needed before implementing the on-the-field validation and the remaining assessment steps.

Introduction

Real-world gait data collection has been extensively studied and promoted [1]. Many gait analysis wearables are now available [1], smart shoes and insoles being frequently used [2]. The TOLIFE project uses a smart shoe prototype and AI-based algorithms to effectively detect gait phases [3]. The shoes are equipped with the inertial unit and three embedded resistive force sensors (FSR402, Interlink El.). This study investigated expanding the shoes' measurement capabilities to include dynamic foot pressure mapping and performed a first comparison with a reliable pressure measurement wearable device (Pedar-X, Novel$_{\text{GmbH}}$) under controlled conditions. Results and possible artifacts from the current sensor assembly were discussed, to guide a device re-engineering before proceeding with a thorough on-the-field validation.

Methods

The FSRs (active ⌀12.7mm) are placed (Fig. 1A) under the heel (P1), lateral forefoot (P2), and medial forefoot (P3). A representative healthy subject wore the smart shoes with a same-size pair of Pedar insoles, and walked on a passive treadmill at a self-selected constant speed for one minute. Data were collected simultaneously (50Hz) and aligned offline using the first step. For each foot, three sets of Pedar sensors were associated with the FSRs (Fig. 1A). From each set, the instantaneous maximum (Peak, P*n*P) and average (Mean, P*n*M) pressure curves were computed throughout the signals. Cycles (stance phases) were defined based on the first and last sample with at least one active sensor. Data analysis (OriginPro 9.9; R3.6.0) included: visual and correlation analyses of cycles (Pearson's, $p<0.05$), correlations of each cycle's global values (maximum, mean, and impulse), and statistical non-parametric mapping of normalized and resampled cycles (Wilcoxon, paired samples, $p<0.05$).

Results and Discussion

30 consistent cycles were analyzed per foot (0.86s±3.4%). The prototype dataset missed 1 sample every 6 cycles on the right shoe and 1 every 3 on the left, but only during swing phases. Stance phases were highly consistent between the two devices, differing for 1 sample only in <10% of cycles. The time-processes averaged %RMSE ranged 20-25% for both systems and all sensors. P1-right was acceptably similar to P1P and P1M (19.7 and 14.6% difference in curve areas; Fig. 1B), while P2 and P3 differed up to 93% (Fig. 1C). P1-right also exhibited near-linear correlation with both curves (R^2=0.94) and statistically significant similarity at 6-9% and 22-36% of the cycle (Fig. 1B). Global values showed strong correlations (R^2: 0.69-0.97) but for P3-right. Interestingly, curve patterns suggested that uncontrolled sensor-connection bending likely caused earlier P2 and P3 activation and delayed P1-left deactivation. Further, P3 instability was supposed to be partly due to its position beneath the 1stMPJ (instead of either the 1st metatarsal head or the hallux proximal phalanx).

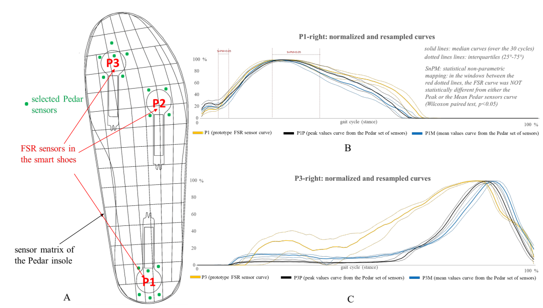

Figure 1: A: matching of smart shoe FSRs and Pedar sensor matrix. B. P1-right: median and interquartile curves from the two devices. C. P3-right: median and interquartile curves from the two devices.

Conclusions

The smart shoes had already been proved effective for gait phases detection. Our exploratory investigation highlighted its potentialities and current limitations to also deliver a reliable proxy of the plantar loading pattern. While it seems worth to address this goal, an ad-hoc re-engineering of some mechanical details is recommended for a higher signal reproducibility and the reduction of bending-related artifacts.

Acknowledgments

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References

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