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A 3D Force Measuring Insole for Athlete Training and Readiness Monitoring

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Introduction

Although the demand for wearable technology for sports performance research and individual athlete monitoring is on the rise[1] the current options for achieving this are limited. GPS and accelerometry based wearables lack important 3D ground reaction force (GRF) based metrics, and force plates are limited to snapshots of data, rather than continuous monitoring during practice or game sessions.

The purpose of this project is to validate a novel 3D force and motion sensing shoe insole, based on a smart material technology[2,3], for 3D ground reaction force measurement and gait feature recognition. The overall goal is to prove its potential for providing external load monitoring and athlete readiness assessments in a single wearable package.

Methods

For gait metric validation, 2 pairs of women's size 6 and 1 pair of men's size 12 were provided. A GAITRite gait mat was used to validate 27 distinct temporal gait metrics. The insoles were inserted into standard athletic shoes and worn by the researchers for several trials that were varying in length and included some trials of irregular gait. In total, 27 trials of viable data were collected.

For 3D force validation, 4 women's size 6 insoles and 4 men's size 12 insoles were provided. A BERTEC force plate was used to validate the X, Y, and Z force data. The insoles were worn by five researchers over 13 trials of squats, bouncing, and adduction/abduction. The right and left insole data was time synced and calibrated through an optimization algorithm.

GAIT METRIC DETECTION

Figure 1: A representative Force vs Time chart for a single gait analysis trial

Movement	MPE
Cadence	0.3%
Step Time	9.8%
Single Sup. Time	1.0%
Gait Cycle Time	6.7%
Stance Time	2.2%

Table 1: Mean Percent Error for Each Movement

3D FORCE VALIDATION

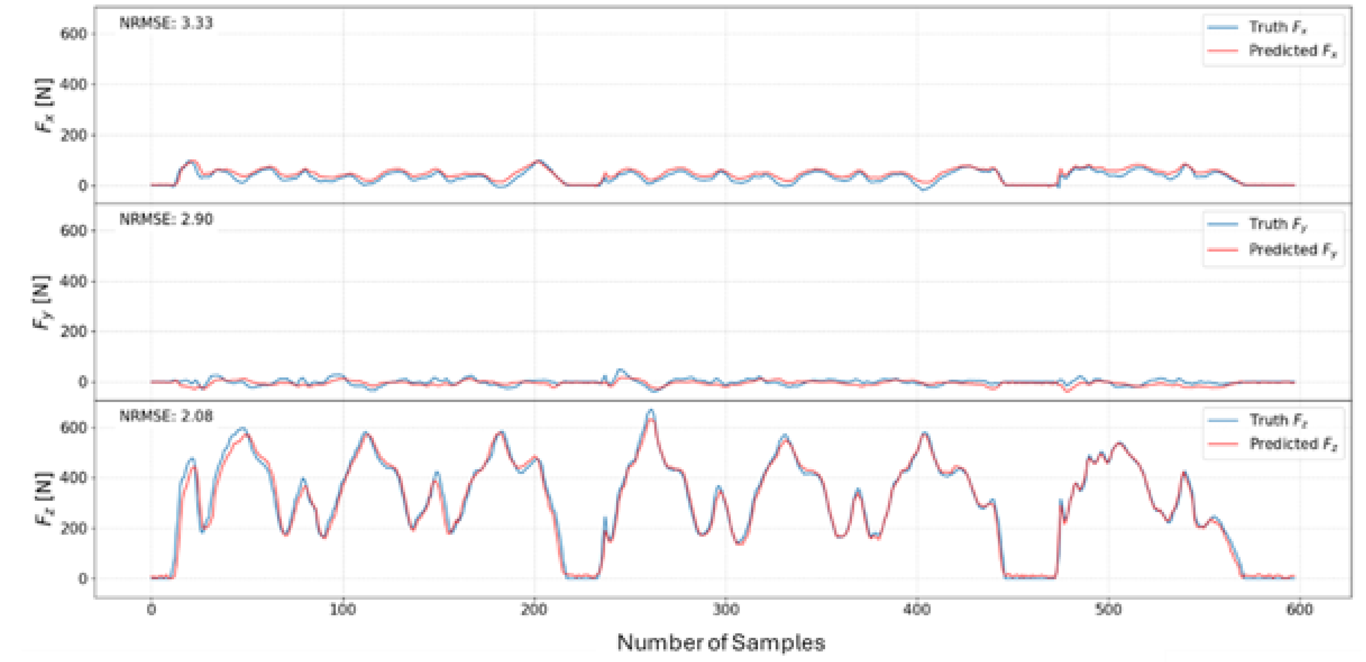

Figure 2: Representative graph of the squats portion of a trial. The blue line represents the data from the Bertec force plate, while the red line represents the data from the insole

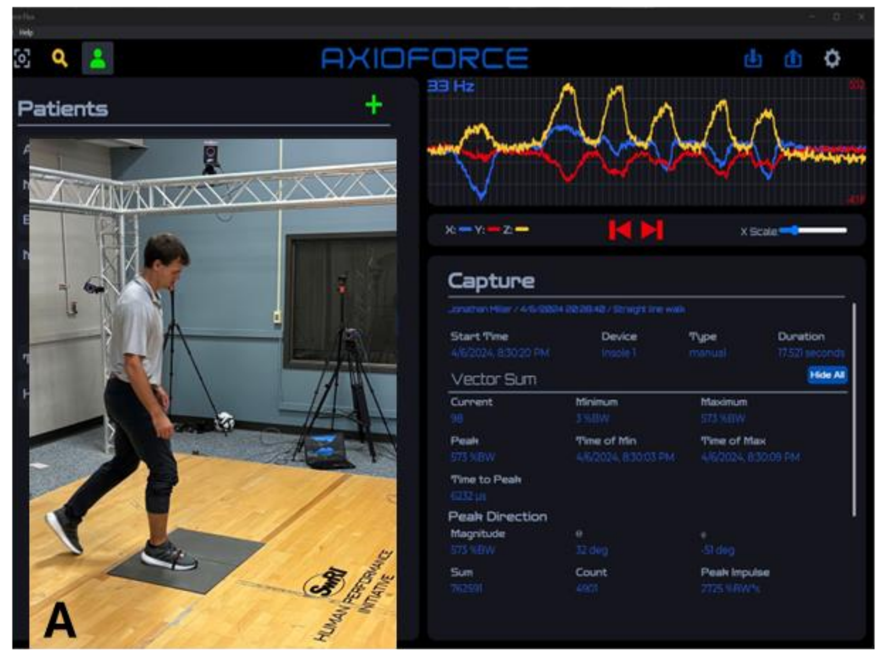

Figure 3: Researcher steps onto force plate wearing insoles to collect force data

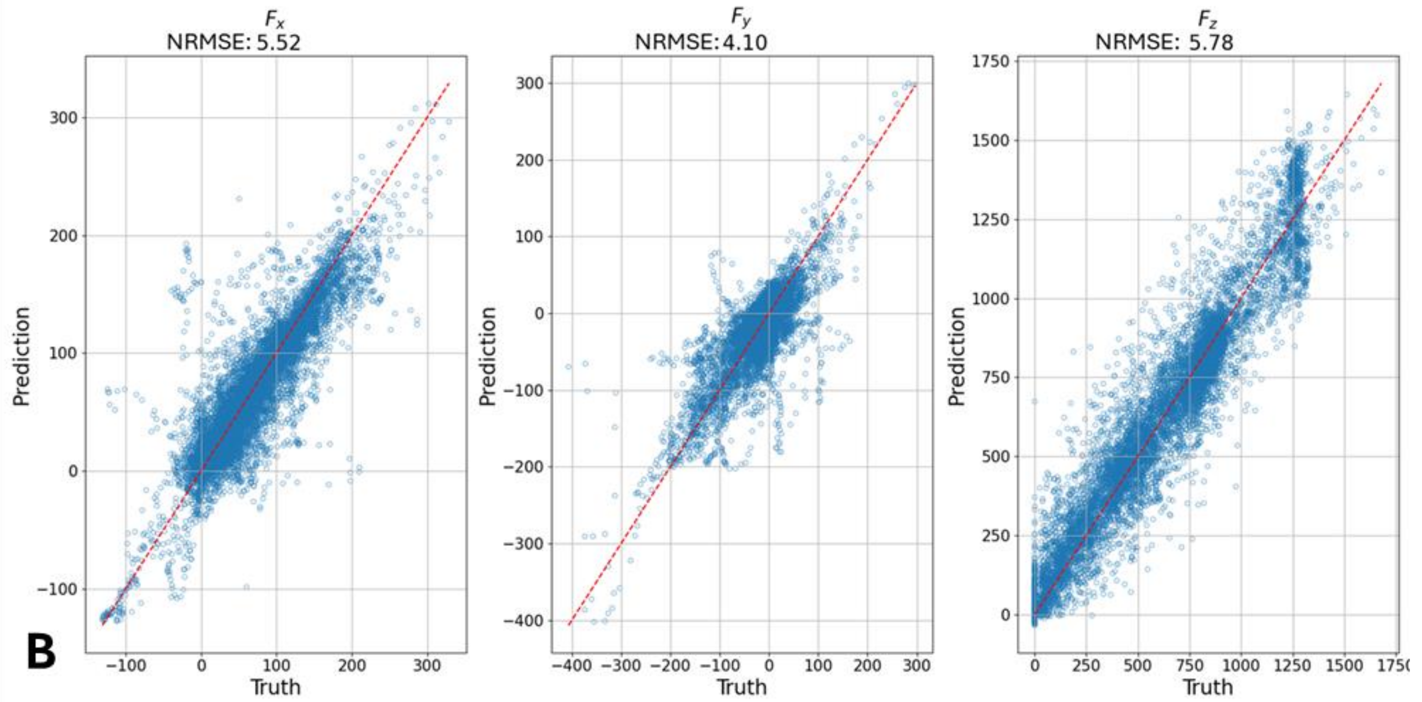

Figure 4: Truth data vs insole prediction of one trial for X, Y, and Z, respectively

Figure 5: Finished insole being inserted into shoe

Results

A time-interpolation method to address data frequency inconsistencies. Heel strike and toe off points were identified using a vertical force threshold. Five gait metrics were calculated based on these points. The insoles achieved 90% accuracy in gait metric predictions. Mean percent error for each metric can be found in Table 1.
In 3D ground reaction forces, the overall normalized root mean square error (NRMSE) was calculated as 4.34, 3.92, and 6.78 for F_x, F_y, and F_z, respectively. An example movement pattern shown as a 3D ground reaction force chart is shown in Figure 2.

Conclusions

The insoles were successful in their ability to accurately predict 3D ground reaction forces and gait metrics. There is strong indication for future external load monitoring and athlete readiness monitoring from a single, convenient-to-use wearable shoe insole. The combination of accurate 3D force and gait event detection makes for a convenient, multi-use, wearable shoe insole to monitor the progress of rehabilitating athletes, track progression of force production, and various other applications.

References and Acknowledgements

(1) Luczak, T., Burch, R., Lewis, E., Chander, H. & Ball, J. State-of-the-art review of athletic wearable technology: What 113 strength and conditioning coaches and athletic trainers from the USA said about technology in sports. International Journal of Sports Science & Coaching 15, 26–40 (2020).
(2) Miller, J. D., Cabarkapa, D., Hermes, M. J., Fry, A. C. & Berkland, C. J. Soft Magnetic Composites as Quantitative 3D Compression Sensors for Wearable Technology. Advanced Materials Technologies 7, 2100784 (2022).
(3) Miller, J. D. et al. Novel 3D Force Sensors for a Cost-Effective 3D Force Plate for Biomechanical Analysis. Sensors 23, 4437 (2023).

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