Ear-worn inertial sensors can estimate scalar kinetic gait metrics and reconstruct vertical ground reaction force curves during running.

Jake Stuchbury-Wass[1], Mathias Ciliberto[1], Kayla-Jade Butkow[1], Qiang Yang[1], Yang Liu, [1]
Ezio Preatoni[2], Dong Ma[3] and Cecilia Mascolo[1]
[1]Department of Computer Science and Technology, University of Cambridge, Cambridge, UK
[2]Department for Health, University of Bath, Bath, UK.
[3] School of Computing and Information Systems, Singapore Management University, Singapore
Email: js2372@cam.ac.uk

Summary

Ear-worn wearables are widely used while running for entertainment and many modern devices include inertial sensors for user interaction. We propose using earbuds equipped with inertial sensors to estimate the vertical ground reaction forces (vGRFs) from the vibrations transmitted to, and motion of the head. We devised a gait event detection and use this segmentation to train and validate a regression model to predict the vGRFs. Our results showed good agreement with the instrumented treadmill with an average MAPE of 3.97% on scalar GRF derived metrics, showing the promise of ear worn devices for detailed running gait analysis.

Introduction

Measuring musculo-skeletal loads is a fundamental aspect for performance and injury prevention during physical activity. However, measurements are typically confined to lab environments, thus, wearables have the potential to be used in-field, but need proper validation [1]. While running, smart watches suffer from large motion artifacts and specialist devices such as hip or shoe pods are owned by a minority of people. Ear worn devices, however, are positioned well in a stable location and are commonly worn for entertainment. Modern devices (i.e. Apple Airpods Pro) feature IMU sensors used for user interaction which can be used for sensing. We propose using these devices for measuring three scalar kinetic gait metrics, loading rate (LR), peak force (PF), and impulse as well as reconstructing the vGRF curve while running and aim to validate it in this study.

Methods

We collected data from 30 participants (18 males, 12 females) who each performed three 4-minute runs, including 10 km/h speed which was common to everyone. We used a Bertec Instrumented Treadmill (1000 Hz) to collect vGRF data and the OpenEarable 1.4 [2] to collect IMU data from both ears. The IMU was a 9-axis Bosch BMX160 sampled at 100 Hz.

We developed an algorithm that first uses a novel gait event detection based on IMU signal features, including consistent zero crossings and sharp peaks, unique to the head while running. This algorithm segments IMU data into foot contact times. This information is used to make predictions of ground reaction forces through a Gaussian Process regression model. For vGRF estimation, a boosted regressor model was trained on a uniformly resampled stance phase, the input being the scalar gait metrics and the segmented IMU sequence.

Results and Discussion

Our approach is validated with a leave-one-subject-out (LOSO) validation which better mimics the expectations of such an algorithm in real deployment. We use the Mean Absolute Percentage Error (MAPE) of our models to assess scalar performance and Normalised Root Mean Square Error (NRMSE) for vGRF reconstruction.

Our results show good agreement between the instrumented treadmill and the ear-worn device estimated metrics, in (Table 1). Additionally, the ear-worn devices can capture variations in the vGRF curve between participants with different running styles, one case with a reduced impact peak is in (Fig. 1). Particularly, the earables capture variations in the loading rate and loading period of the vGRF well, we expect this is from the large initial vibration from the heel strike.

Table 1: Results for scalar parameters and vGRF reconstruction

Metric	LR	PF	Impulse	vGRF
Error type	MAPE	MAPE	MAPE	NRMSE
LOSO	7.14%	2.81%	1.97%	5.27%

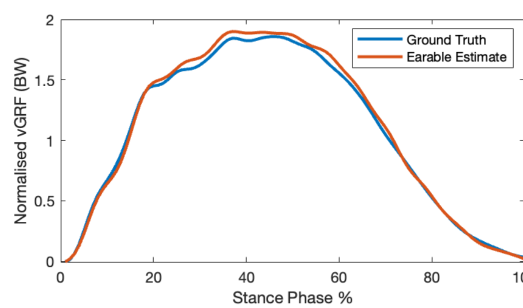

Figure 1: Example estimated vGRF curve from an earable devices.

Conclusions

We show for the first time that ear worn wearables with inertial sensors, a common commodity device, are capable of estimating ground reaction forces during running. This gives a promising device for improving running training and injury prevention for athletes using devices many already own.

References

[1] Preatoni, E., et al. (2022). Sensors, 22(9), 3225.
[2] Röddiger, T., et al. (2024). *Proceedings 1st Workshop on Open Wearable Computers collocated with UbiComp'24*