Monitoring Walking Gait Parameters with Earables

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Introduction

Gait analysis, the study of human locomotion, is crucial for clinical evaluations and wellness monitoring. Gait analysis has wide-ranging applications in rehabilitation, sports science, fitness monitoring [1], and clinical settings, aiding in injury detection, gait disorder identification, and early diagnosis of conditions like Parkinson's disease. Walking gait parameters can be categorized into *temporal* (e.g., cadence, stride, stance, and swing time), *spatial* (e.g., step length and vertical displacement), and *kinetic* (e.g., ground reaction forces, joint torques). While temporal and spatial parameters are commonly assessed and associated with overall fitness levels and neurological conditions, kinetic parameters offer additional insight into biomechanical determinants of movement and the loading of anatomical structures.

Outside of the lab, wearables are the main method for gait assessment. Current methods for wearable gait analysis involves attaching IMU sensors to the shoes, ankles and lower back. However, these devices are purpose made with only a singular use case and can be socially unacceptable or unconformable to wear. To address these issues, some researchers have explored using commercial wearables like smartwatches, however, these have been shown to have limitations in assessing gait metrics.Additionally, wearable studies typically focus on specific subsets of gait parameters for particular applications, lacking a versatile monitoring tool that benefits a broad population where a pathology may also be unknown.

Methods

To solve these problems, we propose an ear-worn wearable, or *earable*, based walking gait monitoring system. Compared to other wearable form factors, earables are desirable as they are widely available and have dual elements that are located centrally and symmetrically in the body, allowing symmetric monitoring of both feet. Additionally, the human head exhibits high stability during walking, which incurs limited interference and thereby enables accurate gait monitoring. Additionally, our system can simultaneously measure temporal, spatial, and kinetic parameters. We also show, for the first time, that earables are able to reconstruct the vertical ground reaction force (vGRF) curve and scalar parameters as shown in fig. 1 Our system leverages IMUs in earphones to detect gait events and estimate parameters on a step-by-step basis. It employs lightweight signal processing techniques for efficient operation on mobile devices, compensates for different earphone orientations, and mitigates the impact of head movements.

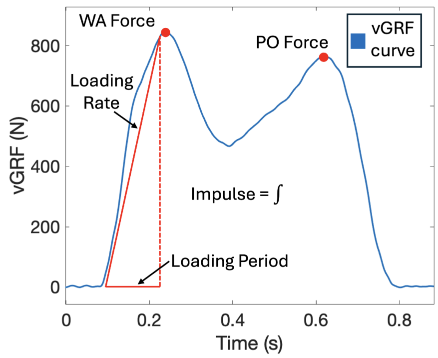

Figure 1: Example walking vGRF curve and scalars

Results

We prototyped our system using custom earphones equipped with 6-axis IMUs. Data was collected from 13 participants who walked in various experimental settings, including lab-controlled conditions on an instrumented treadmill under different walking speeds, in-the-wild evaluation including free-walking on force plates, and a stop-and-go scenario, resulting in over 18,000 step samples. Our system achieves an overall Mean Absolute Percentage Error (MAPE) of 5.1% for spatio-temporal parameters and 2.0% for kinetic parameters, and 5.3% on vGRF curve reconstruction. Compared to existing earable-based gait tracking systems, our system not only expands the coverage of gait parameters but also delivers more accurate estimation with better generalisation ability. A full set of results, benchmarks and on-device performance can be seen in the published version [2].

References

[1] Tingting Wu and Yanan Zhao, "Associations between functional fitness and walking speed in older adults," *Geriatric Nursing*, vol. 42, 2021.

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