VoxNeuro: A Low-Cost, Accessible Multimodal System Integrating Wearable Gait Monitoring and Grassmannian Subspace Analysis of Speech for Parkinson's Screening

Khan, Laiba (School: Lexington High School)

Parkinson's disease (PD) is one of the fastest-growing neurological disorders worldwide, yet objective tools for monitoring speech and gait decline outside specialist clinics remain limited, especially in low-resource settings. A major methodological issue in prior PD speech machine-learning studies is subject leakage: many evaluate individual recordings rather than unseen patients, inflating diagnostic accuracy. We present a leakage-safe, subject-level framework that models each person's repeated speech recordings jointly as a geometric subspace on a Grassmann manifold, then fuses this representation with conventional statistical summaries through principled kernel combination. To address class imbalance, we apply geodesic oversampling on the manifold (G-SMOTE). All evaluations use strict 5-fold subject-disjoint cross-validation, the clinically relevant test of generalization. On two public speech datasets, UCI-489 (80 subjects, balanced) and PD-252 (252 subjects, imbalanced), our method achieved balanced accuracies of 0.850 ± 0.042 and 0.747 ± 0.036 and macro-F1 scores of 0.847 ± 0.043 and 0.756 ± 0.029, outperforming all Euclidean baselines. We also developed a low-cost wearable device for continuous real-world Parkinson's monitoring. Complementary gait analysis showed that PD gait is slower and shorter than control gait, that levodopa produces measurable improvement, and that subject-level models achieved balanced accuracy of 0.812 for PD-vs-control and 0.719 for OFF-vs-ON medication discrimination. Together, these results show that leakage-safe digital biomarkers from speech and gait can improve early recognition of functional decline, support scalable home monitoring and annual screening, and offer a lower-cost alternative to many current systems.

Awards Won:
Westlake University: Westlake University is awarding Pre-college Summer Program Scholarships, covering the program fee, lodging, food, insurance, round-trip international airfare, and excursions in Hangzhou &amp
Shanghai this summer, to up to six finalists.