Artificial-Intelligence Powered Digital Ocular Motor Biomarkers of Parkinson's Disease

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Precision Care Medicine, Design Day 2026

Introduction

- Parkinson's disease (PD) is a rapidly growing neurodegenerative disorder affecting ~10 million people worldwide, characterized by a loss of dopaminergic neurons.
- Common symptoms include tremors, rigidity, and cognitive/sensory decline.
- Current diagnostic approaches are largely subjective and often fail to detect PD during its extended prodromal (early) phase.
- This study builds on the previous team's machine learning framework by training a classifier on generated oculomotor data and multimodal ML techniques.
- By identifying early abnormalities in eye movements as non-invasive biomarkers and addressing data scarcity through synthetic dataset formation, the project aims to enable earlier, safer, and more accurate diagnosis.

Objectives

Our overall goal is to develop a non-invasive, AI-driven framework using digital ocular motor biomarkers for early detection and classification of PD. In particular, are primary aims are to:

- **Model saccades, fixation, and smooth pursuits for healthy and PD patients**
- **Generate multimodal synthetic oculomotor waveforms for each eye movement type**
- **Validate generated synthetic waveforms**
- **Develop a multimodal machine learning classifier for more accurate PD detection**

Methods

1. Known Clinical Parameters

Parameter	Healthy Individuals	Parkinson's
Velocity	High	Reduced
Latency	Low	Increased
Gain	~1	<1
Noise	Low	High

Distinguishing Parkinson's from healthy controls by comparing parameters known clinical parameters

2. Mathematical Models

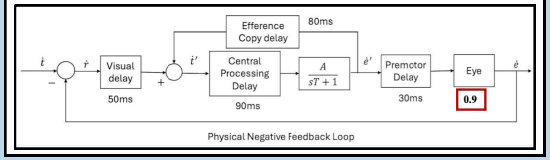
$$v_{sac} = v_{max} \times (1 - e^{-\frac{A}{C}})$$

where:
v_{max} = asymptotic maximum velocity
A = saccade amplitude
C = exponential rise constant

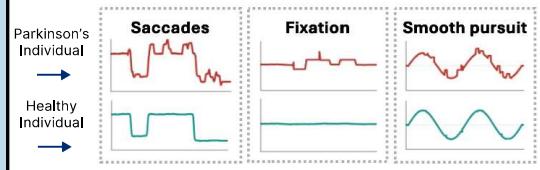
$$d_{sac} = D_1 \times A^n$$

where:
D_1 = duration of a 1° saccade
A = saccade amplitude
n = power constant

Robinson's Model (1956)

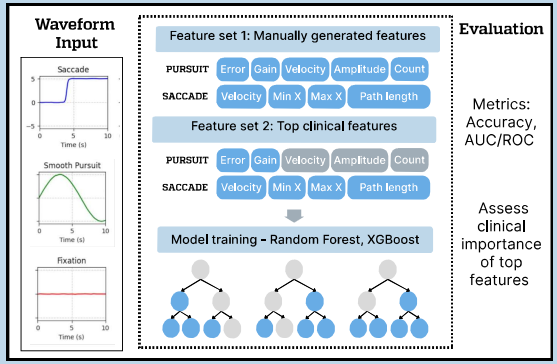


3. Waveform Comparison



Using established models and clinical parameters, we generated synthetic waveforms that capture key Parkinsonian eye movements for comparison with healthy controls

4. Classifier Building

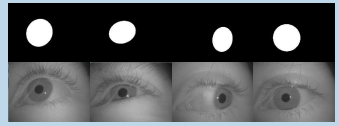


Conclusion

- We generated novel synthetic waveforms of saccades, fixations, and smooth pursuits to improve targeted PD classifiers without depending on large patient datasets.
- **It supports accessible, and objective diagnostic tools by enabling earlier detection, better monitoring, and more personalized treatment of Parkinson's disease.**

Future Directions

Extracting Binary Pupil Mask

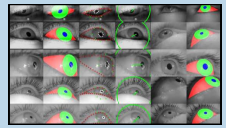


Segmented eye video frame TEyeD: 20 mil images (60 Hz)

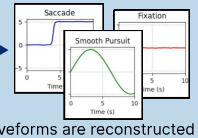
Modified Pose-Based ControlNeXt Image/Video Generation Model

Using the modified pose-based ControlNeXt model, we generate realistic eye movement sequences from synthetic waveforms and extracted pupil masks

Generating and Validating Synthetic Eye Movement Video Data



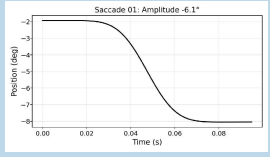
Synthetic waveform–driven eye movement video



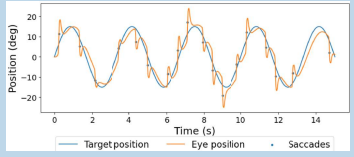
Waveforms are reconstructed and validated against original signals

Results

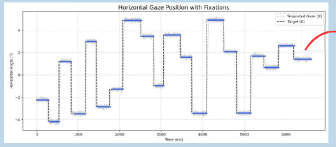
Synthetic Waveform Generation



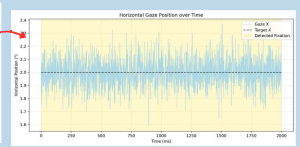
Saccade



Smooth Pursuit with Saccadic Intrusion

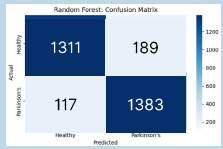


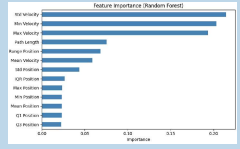
Fixations



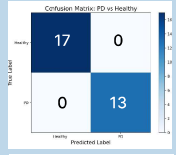
Singular Fixation

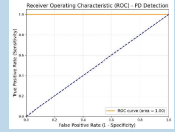
Model 1: Full Manual Feature Set



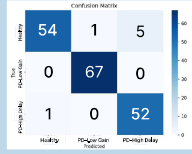


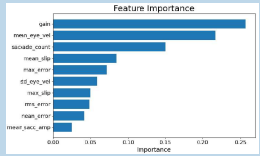
Saccades





Fixations

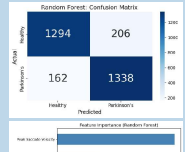




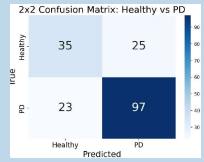
Smooth Pursuits

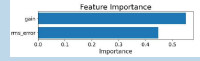
Movement	Accuracy
Saccades	89.8%
Fixations	100.0%
Smooth Pursuits	96.1%

Model 2: Top Clinical Features

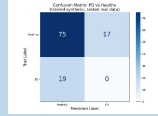


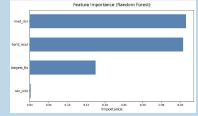
Saccades





Smooth Pursuits





Fixations

Movement	Accuracy
Saccades	87.7%
Fixations	67.6%
Smooth Pursuits	73.3%

Classifiers trained on our novel synthetic dataset show a high accuracy. The primary features identified by models trained on purely synthetic data also align with the clinically determined features. This suggests that the generated synthetic data is still very physiologically faithful.

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Author(s). Article Title. Abbreviated Journal Title. Year;Volume(Issue):Page Range