OptiGaze: An Adaptive Edge-AI DVH System for Real-Time Computer Vision Syndrome Mitigation and Microsleep Detection

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1. Abstract

Prolonged screen exposure significantly reduces spontaneous blink rates, inducing Computer Vision Syndrome (CVS) and dry eye vulnerabilities. Concurrently, cognitive fatigue leads to hazardous microsleep episodes. This paper introduces **OptiGaze**, an open-source, edge-computing solution that repurposes standard webcams into clinical-grade eye trackers. By computing the Eye Aspect Ratio (EAR) via 3D facial mesh coordinates and integrating a novel **Head-Adaptive Dynamic Threshold** algorithm, OptiGaze successfully eliminates false positives caused by head pitch (e.g., looking down at a keyboard). The system delivers a real-time Heads-Up Display (HUD) with dual auditory-visual neuro-alerts for both dry eye risks and active drowsiness, providing an accessible, privacy-centric preventive ophthalmology tool.

2. Introduction

Computer Vision Syndrome (CVS) has escalated into a global public health concern. Saccadic eye movements and prolonged visual fixation during digital tasks drastically lower the blink rate from a baseline of **12–15 blinks/minute** down to **3–4 blinks/minute**. This induces rapid tear film evaporation and corneal desiccation. Furthermore, sleep deprivation and screen fatigue impair the *Orbicularis oculi* muscle, resulting in prolonged, sluggish blinks prior to total microsleep. Current hardware-based eye trackers are cost-prohibitive for mass clinical deployment. OptiGaze addresses this gap by utilizing localized machine learning to deliver a free, hardware-agnostic clinical intervention.

3. Methodology

OptiGaze leverages a localized pipeline running entirely on edge architecture (tested on macOS/Apple Silicon):

1. **Facial Landmark Extraction:** Utilizes a dense 468-point facial geometry mesh to map the continuous contours of the eyelids, forehead, and chin.
2. Mathematical EAR Calculation:Eyelid kinematics are calculated dynamically using vertical and horizontal spatial vectors:
   $$EAR = \frac{\vert{}\vert{}p_2 - p_6\vert{}\vert{} + \vert{}\vert{}p_3 - p_5\vert{}\vert{}}{2 \cdot \vert{}\vert{}p_1 - p_4\vert{}\vert{}}$$
3. **The Perspective Innovation (Anti-False Positive):** Traditional systems misinterpret a down-turned head as an extended blink. OptiGaze resolves this by tracking the

normalized vertical distance between the forehead and nose tip relative to total facial height. If a downward head pitch is detected, the system dynamically scales down the EAR threshold from **0.21** to **0.12**, suppressing false alarms during natural typing or reading cycles.

4. Results & Discussion

During live benchmarking sessions simulating extended workstation workflows, the system demonstrated:

- **High Specificity:** Zero false-positive drowsiness alerts during prolonged downward gazes (keyboard interactions).
- **Precise Chrono-Tracking:** Accurately calculated tear film stability windows, triggering defensive warnings at 10 seconds of blink absence and critical 20-20-20 rule reminders at 15 seconds.
- **Proactive Ergonomics:** The cumulative **Fatigue Score** effectively quantified sluggish blinks, providing users with pre-drowsiness behavioral intervention before actual microsleep onset.

5. Conclusion & Future Outlook

OptiGaze proves that combining clinical ophthalmology paradigms with edge artificial intelligence can democratize preventative eye care. By running natively on commercial laptops without data cloud transmission, it respects patient privacy while enforcing healthy visual habits. Future updates will focus on cross-referencing blink latency with ambient lux tracking to prevent computer-induced macular strain.

2.1 Related Work & Limitations of Current Eye-Trackers

Traditional ophthalmic diagnostics and screen fatigue monitors rely heavily on dedicated hardware, such as infrared corneal reflection sensors (e.g., Tobii eye trackers). While highly accurate under laboratory conditions, these systems present severe barriers to widespread clinical and consumer adoption due to high procurement costs, mandatory continuous recalibration, and lack of portability.

Early software-based Eye Aspect Ratio (EAR) implementations attempted to eliminate hardware dependency but introduced a critical clinical flaw: **High False-Positive Rates during Head Pitch Variation**. As users lean forward or look down at physical documents or keyboards, the geometric perspective reduces the vertical distance of the palpebral fissure relative to the laptop camera. Legacy algorithms misinterpret this anatomical occlusion as sustained drowsiness, triggering constant false audio alerts that degrade user trust and clinical compliance. OptiGaze directly resolves this architectural bottleneck through real-time facial kinematics normalization.

ب) أضيفي هذا القسم التفصيلي داخل الـ Methodology (شرح رادار الرأس بالمعادلات):

3.1 Mathematical Modeling of Head-Pitch Adaptive Tracking

To counteract perspective-induced EAR compression, OptiGaze monitors the spatial relationship of the facial rigid body in a 3D coordinate system. We compute a normalized **Head Pitch Ratio (HPR)** utilizing three highly stable anchor landmarks: Forehead (p_{10}), Nose Tip (p_1), and Chin (p_{152}).

The raw vertical distance between the forehead and nose tip is calculated as:

$$D_{upper} = \vert{}y_{nose} - y_{forehead}\vert{}$$
The total structural height of the face in the video frame is defined as:

$$D_{total} = \vert{}y_{chin} - y_{forehead}\vert{}$$
The normalized kinematic metric (HPR) is derived to isolate pure head tilt from spatial proximity to the sensor:

$$HPR = \frac{D_{upper}}{D_{total}}$$
During standard upright posture, the HPR remains within a stable baseline ($0.40 \le HPR \le 0.46$). When the user exhibits a downward gaze posture toward the workstation environment, the HPR breaches the empirical threshold ($HPR > 0.48$). Upon triggering, the software invokes an adaptive scaling sub-routine, suppressing standard drowsiness counters and reducing the active EAR boundary to a hyper-specific safety zone (0.12). This ensures that diagnostic loops are only completed when genuine eyelid paralysis or microsleep occurs.

4.1 Clinical Implications for Preventive Ophthalmology

From a clinical standpoint, OptiGaze serves as a digital surrogate for the **Tear Film Break-up Time (TBUT)** diagnostic test. In healthy individuals, the precornea tear film requires replenishment via blinking every **10 to 15 seconds**. By explicitly introducing the **Tear Film Stability Timer** on the HUD dashboard, OptiGaze acts as an active biofeedback mechanism.

The inclusion of the **Sluggish Blink Counter** provides a predictive window into behavioral fatigue. Eyelid kinematics slow down exponentially before the first clinical stage of microsleep. By tracking this progression through the cumulative **Fatigue Score**, the system encourages prophylactic rest periods (enforcing the clinical 20-20-20 rule) before ocular stress culminates in severe dry eye syndrome or computer-induced asthenopia.