

Eye-Tracking Without Goggles: A TinyML Brim-Based Eye-Tracking System with Digital Mimic

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Supplementary Figures

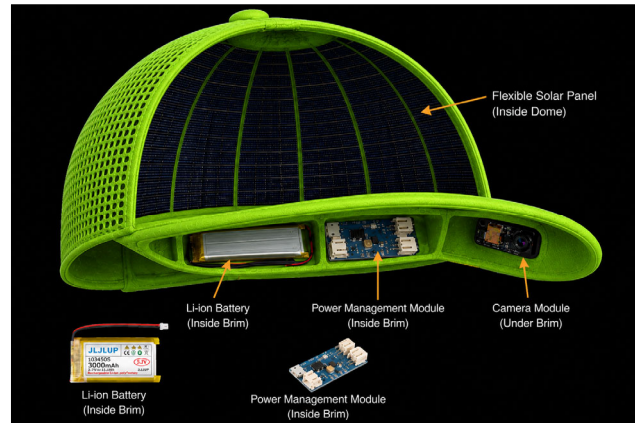


Figure S1. Physical integration of the proposed self-powered eye-tracking microsystem within the 3D-printed TPU hat.

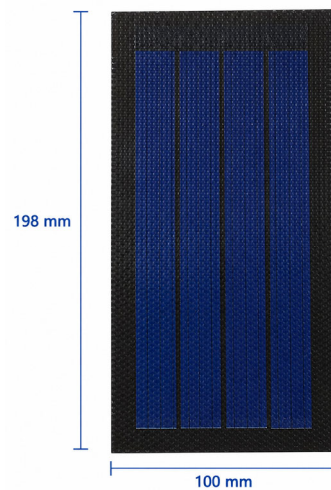


Figure S2. Flexible solar panel and its dimension.

Table S1. Eye-State Classification Performance Across Dataset Splits

Dataset Split	Precision	Recall	F1-Score	Classification Accuracy
Train Set	0.992	0.988	0.990	99.1%
Validation Set	0.978	0.965	0.971	97.2%
Test Set (Held-Out)	0.964	0.952	0.958	95.8%

Table S2. System latency

Pipeline Stage	Module / Process	Latency (ms)
1. Image Acquisition	OV3660 camera capture (96 × 96 grayscale @ 25 Hz)	40.0 ms
2. Preprocessing	Downsampling (64 × 64) + Histogram Equalization	3.2 ms
3. Edge AI Inference	INT8 CNN execution on ESP32-S3 Vector Extension	14.6 ms
4. Post-processing	Temporal filtering & eye-presence voting	0.8 ms
5. Wireless Transmission	BLE 26-byte payload transmission (@ 20 ms connection interval)	18.4 ms
6. Mobile Rendering	Swift packet parsing & Unity 3D update	4.2 ms
7. End-to-End Latency	Acquisition to Mobile Render	81.2 ms

Pipeline Stage	Module / Process	Latency (ms)
8. System Sampling Rate	Achieved Frame Rate	22.5 FPS / Hz

Table S3. Active Hardware Power Consumption Budget

Hardware Component	Operating Voltage	Current Demand	Power Demand
2× ESP32-S3 MCUs (Active Inference + BLE)	3.3 V	200.0 mA (combined)	660.0 mW
2× OV3660 Cameras (\$96 \times 96\$ Capture)	3.3 V	36.0 mA (combined)	118.8 mW
1× MPU6050 6-Axis IMU	3.3 V	3.8 mA	12.5 mW
Total Active System Demand			791.3 mW

Table S4. Quantitative comparison of your proposed Solar-Assisted Hat System against standard headwear

System	Weight	Payload Weight	Facial / Nose Bridge Pressure	Pitch & Roll Accuracy (MAE)	Yaw Drift Rate	Lighting Sensitivity
Proposed Word	192 g (185–202 g)	92 g	0 g (100% distributed on	1.1° (MPU6050 + filter)	0.8° / min (uncalibrated)	500 to 100,000 lux (Δ MAE < 0.25 px)

System	Weight	Payload Weight	Facial / Nose Bridge Pressure	Pitch & Roll Accuracy (MAE)	Yaw Drift Rate	Lighting Sensitivity
			<i>crown/brim)</i>			
Standard Baseball Cap	85–115 g	0 g	0 g	N/A	N/A	N/A
Tobii Pro Glasses 3	76.5 g (<i>head unit</i>)	76.5 g (+312 g <i>belt unit</i>)	100% on nose bridge/ear s	< 0.5° (<i>optical gaze</i>)	< 0.2° /min	100 to 50,000 lux (<i>IR illuminators</i>)
Pupil Labs Neon	50–80 g (<i>frame depend ent</i>)	7.3 g (<i>module + phone tether</i>)	100% on nose bridge/ear s	< 0.60° (<i>optical gaze</i>)	< 0.2° /min	Indoor / Outdoor (<i>IR illuminated</i>)
Apple Vision Pro	~600– 650 g	~650 g	Severe facial/ch eck pressure	< 1.0° (<i>internal gaze</i>)	< 0.1° /min	Indoor to controlled ambient
Meta Quest Pro	~722 g	~722 g	Distribut ed halo frame	< 1.5° (<i>internal gaze</i>)	< 0.1° /min	Controlled indoor illumination