

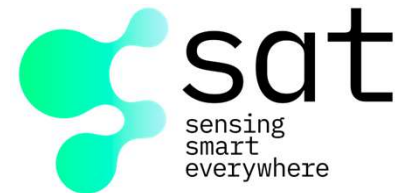
The 10th International Conference on Driver Distraction and Inattention (DDI2026)

Drowsiness and sleep prediction via imaging PPG: a multi-scenario validation from Simulated to Naturalistic Driving

Michele Guagnano, Sara Groppo, Andrea Romigi, Riccardo Groppo, Massimo Violante



**Politecnico
di Torino**



Background – Driver Monitoring Systems (DMS)

~1.2 million
Annual road fatalities worldwide

Source: WHO Global Status Report on Road Safety (2023)

10-30%

Of fatal road accidents directly linked to
driver fatigue and drowsiness

Source: NHTSA / AAA Foundation for Traffic Safety

Vehicle-based (Steering & Lane Departure)

[+] **Non-intrusive:** native and straightforward CAN-bus integration.

[-] **Road dependent:** can be confounded by road geometry.

Behavior-based (PERCLOS & Eye blinking)

[+] **Fully contactless:** relies on standard cabin cameras.

[-] **Reactive detection:** alerts only after eye closure or microsleep.

Physiology-based (ECG & EEG)

[+] **Early prediction:** tracks autonomic state before physical failure.

[-] **Intrusive:** requires direct contact and wired electrodes.

Background – Polysomnography (PSG)

Polysomnography (PSG)

A comprehensive multi-channel diagnostic assessment that records physiological signals (EEG, EOG, EMG, and ECG) across the sleep-wake cycle.

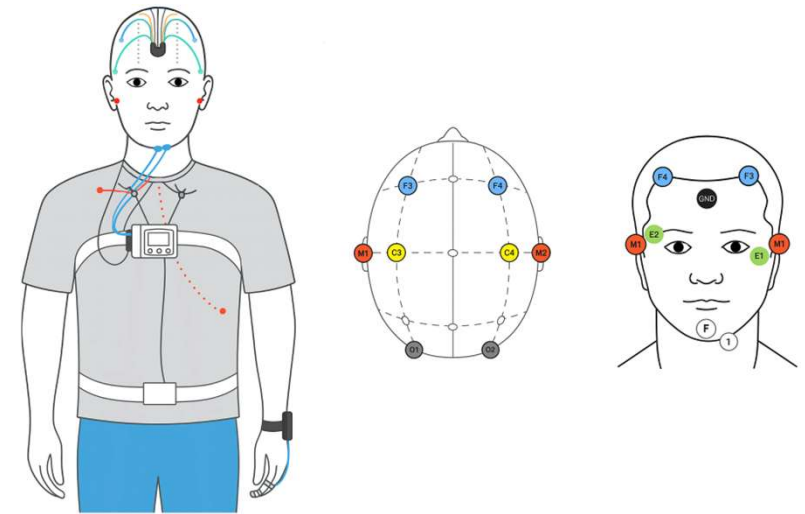
Gold Standard

It represents the clinical gold standard under AASM guidelines for objective sleep staging and serves as the definitive medical ground truth for identifying microsleeps and vigilance transitions.

Pros and cons

[+] Highest reliability: It's the most reliable test for sleep studies.

[-] Invasive: requires direct contact, wires, and time.



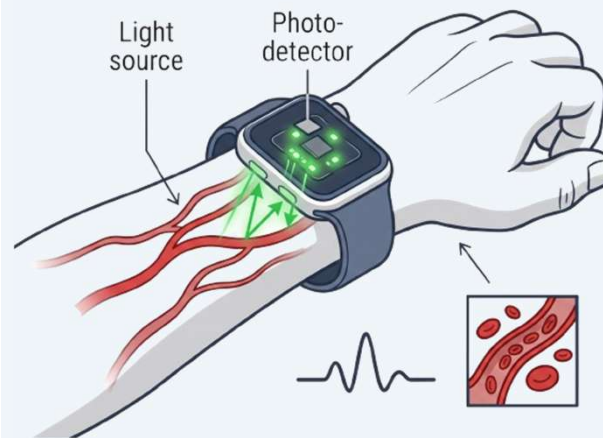
Background – Photoplethysmography (PPG)

Clinical Transmission



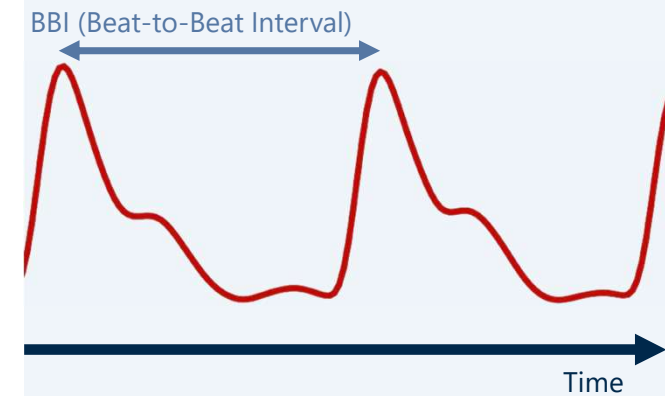
- Light Source shines through tissue.
- The photodetector captures transmitted light on the other side.
- Measures light absorption changes.

Consumer Reflection



- Light Source onto skin surface.
- The photodetector captures reflected light.
- Measures backscattered light.

PPG Signal



- Each cardiac cycle generates a distinct systolic peak corresponding to maximum arterial microvascular volume.
- Peak detection algorithms compute the Beat-to-Beat Interval (BBI).

Background – Imaging PPG



Subsurface Blood Pulse

NIR camera captures micro-variations in cutaneous reflectance from facial vascular beds.



Cardiac Metric Extraction

Extracts instantaneous Photoplethysmography (PPG) without body sensors.



Sleepiness Prediction

HR is processed to look for the physiological behavior that precedes sleepiness and to generate an alarm.

Methodology – Near InfraRed (NIR) iPPG

01 Non-invasive Sensing (NIR iPPG)

Active near-infrared facial illumination for optical signal acquisition
Ensures total driver unobtrusiveness, invariant to nocturnal automotive lighting shifts

02 BBI Extraction & Drowsiness Modeling

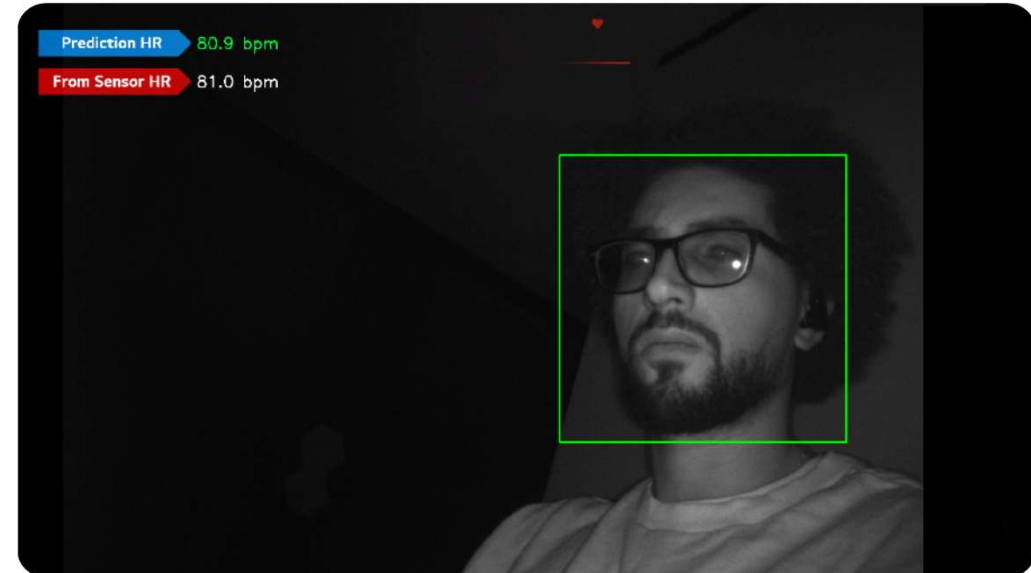
Facial ROI tracking, PPG detection, and BBI Computation
Real-time tracking of autonomic shifts (HRV dispersion) minutes before sleep onset

03 Multimodal Ground Truth Synchronization

Subject monitoring using medical polysomnography (PSG Noxturnal A1)
Extracts continuous clinical EEG/ECG to establish an objective baseline

04 Clinical Sleep Scoring Benchmark

Algorithm events compared to medical scoring.
Direct validation on true microsleep episodes and standardized maintenance tests



Camera HR

Polar HR

Face rec

Methodology – Multistage Algorithm

STAGE 1 - TEMPORAL WINDOWING

Sliding Time Buffer

Collects incoming streams of instantaneous HR and BBI; Discards oldest values dynamically.

Calculated Metrics:

- Mean Heart Rate (mHR)
- BBI Std Dev (sBBI)

STAGE 2 – DYNAMIC DERIVATIVES

Derivative & DOD Tracking

Computes the first derivative of sBBI and stores it in dsBBI. When autonomic tone shifts toward vagal relaxation, the Duration of decrement (DOD) increases.

DOD Increment Condition:

- $mHR < mTh$
- $dsBBI < sTh$

$Cnt = \max(DOD)$

STAGE 3 – STATE CLASSIFICATION

Level 1 - AWAKE

$Cnt \leq Th1$: Physiological equilibrium.

Level 2- FATIGUE ONSET

$Th1 < Cnt \leq Th2$: Vagal rise (Early warning).

Level 3- DROWSINESS ONSET

$Cnt > Th2$: Sleep or microsleep prediction (Alarm).

Methodology – State Classification and meaning

LEVEL 1 - WAKEFULNESS

The driver is awake

No alarm is provided

LEVEL 2 – FATIGUE ONSET

Oculomotor biomarkers of drowsiness

Slow Eye Movements or
Oculomotor Activity detected

LEVEL 3 – DROWSINESS ONSET

Microsleep or Sleep

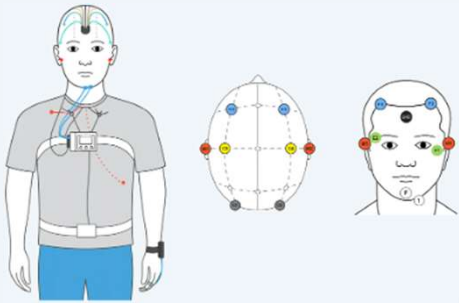
Microsleep, N1 stage, N2 stage
predicted

Oculomotor biomarkers: *Objective metrics of eye-movement dynamics (e.g., Slow Eye Movements – SEM) that physiologically indicate the **transition from active wakefulness to drowsiness**.*

Microsleep: *Brief, involuntary lapses of wakefulness lasting 3 to 15 seconds, characterized by sleep-like EEG activity and a temporary loss of behavioral responsiveness*

Methodology – Validation

1. MWT (CLINICAL TEST)
2. STATIC DRIVING SIMULATOR
3. DYNAMIC DRIVING SIMULATOR



4. NATURALISTIC DRIVING



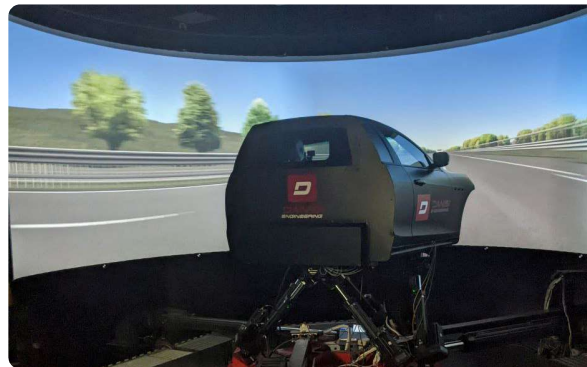
Source: L. Pugliese, M. Violante, and S. Groppo, "A novel algorithm for detecting the drowsiness onset in real-time," IEEE Access



1. MWT (CLINICAL TEST)



2. STATIC DRIVING SIMULATOR



3. DYNAMIC DRIVING SIMULATOR



4. NATURALISTIC DRIVING

Results – Performance Metrics & Multiscenario Validation

92.6%

Sensitivity

25/27 identified
events

82.4%

Specificity

14/17 identified
awakes

88.6%

Accuracy

Based on all the 19
tests

Test ID	TP	FP	TN	FN	Notes
MWT (Clinical)					
Mwt_P1	5 (5F)	0	0	0	Dark skin
Mwt_P2	11 (4M, 1S, 6F)	0	0	1 (1M)	
Mwt_P3	0	0	1	0	
Mwt_P4	0	0	1	0	
Static Simulator					
Static_P1	0	0	1	0	Takes Betablockers
Static_P2	0	0	1	0	
Static_P3	2 (2F)	3	0	0	
Static_P4	0	0	1	0	
Static_P5	1 (1F)	0	0	0	Dark skin
Static_P6	0	0	1	0	
Dynamic Simulator					
Dynamic_P1	0	0	1	0	Dark skin
Dynamic_P2	0	0	1	0	
Dynamic_P3	6 (6F)	0	0	1 (1M)	
Dynamic_P4	0	0	1	0	
Real-World Driving					
Real_P1	0	0	1	0	Takes Betablockers
Real_P2	0	0	1	0	
Real_P3	0	0	1	0	
Real_P4	0	0	1	0	
Real_P5	0	0	1	0	Dark skin
Total	25	3	14	2	

Abbreviations: TP = True Positive, FP = False Positive, TN = True Negative, FN = False Negative
F = Fatigue, M = Microsleep, S = Sleep Event

Conclusions & Future work

Contactless Prediction

Contactless NIR imaging reliably captures autonomic precursors of fatigue minutes ahead of behavioral failure.

Medical Validation

PSG benchmark confirms high diagnostic coherence (92.6% sensitivity) across progressive dynamic environments.

Future work

Expand on-road cohorts, validate across multiple phenotypes, and adapt the algorithm for pharmacologic confounders.

The 10th International Conference on Driver Distraction and Inattention (DDI2026)

Thank you for your attention

Michele Guagnano, Sara Groppo, Andrea Romigi, Riccardo Groppo, Massimo Violante



**Politecnico
di Torino**

