

Towards in-cabin contactless sleep prediction

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Type

Presentation type: Oral presentation

Please consider this abstract for the Asian Society of Sleep Medicine (ASSM) meeting to be held on Saturday and Sunday, September 6-7, 2025.: Yes

General data

Topic: Technology/Technical

Secondary topic: Excessive Daytime Sleepiness (not Narcolepsy)

Abstract text

Introduction: Drowsy driving is a major cause of fatal vehicle crashes, contributing to 10–30% of all road traffic incidents. Driver monitoring systems are designed to detect drowsiness and are categorized into four main approaches: vehicular-, behavioral-, physiological-, and hybrid-based. Physiological systems are the most accurate, already providing great results exploiting cardiac parameters extracted with contact-based solutions; however, these systems are intrusive and costly.

This work proposes a physiology-based, non-contact method for sleep prediction by analyzing Respiration Rate (RR), acquired on-the-fly using a short-range, 60 GHz, automotive, standalone radar in a driving-seat-mockup and driving-simulator environments. Sleep events were, for the first time in this context, robustly validated by a sleep expert medical doctor using the American Academy of Sleep Medicine (AASM) guidelines for the Maintenance of Wakefulness Tests (MWT) scoring, with a special focus on microsleep events. Therefore, a preliminary solution for sleep prediction in drivers, using RR acquired by radar, was successfully developed and validated.

Materials and methods: The radar detects chest and abdominal motion to estimate RR at 1 Hz. Data are processed offline to simulate real-time operation. A classification algorithm labels each second as ALARM or NOT-ALARM, predicting a potential sleep event.

Participants wore a Polysomnographic (PSG) setup. Data were collected during a modified-MWT conducted in two settings:

- Driving-seat-mockup: 13 subjects (mean age: 39 ± 10, 5 female) sat in a cockpit simulator and followed repetitive driving instructions on a tablet for 40 minutes.
- Driving-simulator: 13 subjects (mean age: 40 ± 20, 4 female) sat in a Maserati Ghibli dynamic cockpit simulator and completed a 45-minute low-stimulus driving session with dim lighting and minimal external input.

Participants were instructed to resist sleep. The PSG data have been scored by a sleep expert medical doctor following the guidelines of AASM. The scored sleep events (Microsleep, NREM1, NREM2, NREM3, REM, Awake) are the Ground Truth labels.

Ground truth was compared against algorithm predictions using a confusion matrix.

Results: Evaluation was based on the timing between the ALARM and the sleep event scored by the medical doctor:

- True Positive (TP): ALARM occurred before the first sleep event.
- False Negative (FN): ALARM occurred after (or concurrently) the sleep event or was not triggered at all.
- False Positive (FP): ALARM was triggered, but no sleep event occurred.
- True Negative (TN): Neither ALARM nor a sleep event occurred.

Therefore, the overall accuracy was evaluated as follows.

- Prediction of the 1st sleep event:

Driving-seat-mockup: 69% (TP=9, TN=0, FP=3, FN=1)

Driving-simulator: 85% (TP=1, TN=10, FP=1, FN=1)

- Prediction of all sleep events:

Driving-seat-mockup 94% (TP=79, TN=0, FP=4, FN=1)

Driving-simulator 80% (TP=2, TN=10, FP=1, FN=2)

Conclusions: This study is a preliminary step towards assessing the feasibility of using RR acquired by an automotive-grade radar in a highly challenging environment for sleep prediction in drivers. Despite the unbalanced and limited sample size of the datasets, the results are promising. More investigations are needed, on the one hand to extend the dataset, on the other to test the radar capabilities in natural driving sessions where motion artifacts can play a significant role in degrading signal quality.

General

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