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Arousal State Assessment Using Blink Pattern Analysis Based on Camera Images in a Simulated Automated Driving Environment

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This study examined whether blink-related indices derived from visible-light camera images can be used to estimate driver arousal in a simulated level-3 automated driving environment. In conditional automated driving, drivers may disengage from continuous manual control but must still respond appropriately to system requests for intervention, making continuous arousal assessment important. Although previous electrooculography studies have shown that blink amplitude and duration vary with arousal, the applicability of camera-based blink features has not been sufficiently verified.

Eight healthy adults participated in an experiment using a driving simulator equipped with three front displays (Fig.1). Facial images were recorded with a web camera installed below the front display. MediaPipe FaceMesh was applied to each frame to detect facial landmarks, and the eye-opening area was calculated from the eyelid region (Fig.2). From the resulting time-series signal, blink waveforms were extracted, and peak amplitude, closing time, and opening time were computed. Blinks were then classified into five patterns (A–E) based on thresholds derived from the initial high-arousal period of each session. The occurrence ratios of patterns A–D (rA–rD), baseline mean (BM), which reflects the eye-opening level, baseline standard deviation (BSD), and blink rate (BR) were calculated and compared with subjective arousal ratings.

The results showed that rA and BM tended to increase with higher arousal, whereas rD and BSD increased with decreased arousal. These tendencies were consistent with previous electrooculography-based findings indicating that pattern A (standard blinks) appears more frequently during high arousal, while pattern D (long-duration blinks) increases with drowsiness. In contrast, pattern B (large-amplitude blinks) and pattern C (small-amplitude blinks) did not show consistent relationships with subjective ratings. Principal component analysis further indicated that rA, rD, BM, BSD, and BR were integrated into the first principal component, suggesting that these indices collectively represent arousal-related variations.

These findings suggest that blink-pattern analysis and continuous eye-opening measures extracted from visible-light camera images provide useful features for estimating driver arousal in automated driving. However, issues such as outlier handling, fixed thresholding, and head-pose changes remain, indicating the need for further refinement and integration with additional physiological indices.

Ethical Approval

This study was approved by the Life Science Research Ethics Committee of Osaka Institute of Technology (Approval No. 2025-24).

Conflict of Interest

The data used in this study were collected through a joint research project with DENSO TEN Limited.

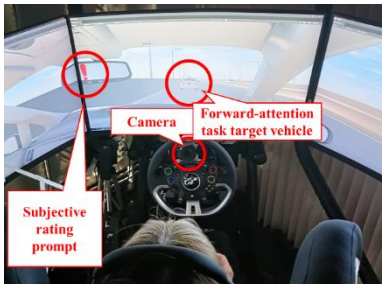

Fig. 1 Experimental driving-simulator setup

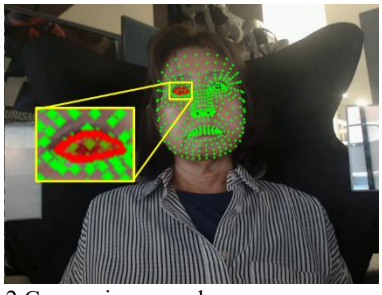

Fig. 2 Camera image and eye-area measurement using FaceMesh (Participant：Author)