

A Study on Estimating Occupant Thermal Comfort Using Facial Expressions and Physiological Indicator

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As vehicle electrification advances, reducing HVAC (Heating, Ventilation, and Air Conditioning) energy consumption while maintaining occupant comfort has become increasingly important. To realize personalized thermal management, real-time estimation of occupant thermal comfort (TC) is required. In this study, a multimodal thermal comfort estimation method using electrocardiogram (ECG) signals and facial expressions was investigated. Figure 1 shows the proposed thermal comfort estimation system. RR intervals (RRI) obtained from ECG signals and facial Action Units (AUs) extracted from facial images were used as input features. RRI-based Lorenz Plot (LP) indices represent autonomic thermoregulatory responses, whereas facial AUs represent affective responses associated with thermal comfort and discomfort.

Thermal exposure experiments were conducted in an environmental chamber under hot (35°C) and cold (15°C) conditions. ECG signals, facial videos, and subjective thermal comfort votes were collected from nine participants. A machine-learning model was developed using LP indices and AUs to estimate TC. Contribution analysis revealed that AU15, AU43, AU26, AU17, AU09, and AU04 showed relatively high importance for TC estimation. These AUs are known to be associated with discomfort, fatigue, aversion, and physical unpleasantness, suggesting that facial expressions reflect affective responses to thermal environments. In addition, LP indices successfully captured autonomic responses under thermal stress. Because LP indices can be calculated from short-term ECG recordings, they are considered practical physiological indicators for real-time in-vehicle thermal comfort estimation.

Figure 2 shows the validation results of the proposed model. The multimodal model combining ECG and facial-expression features achieved a coefficient of determination (R^2) greater than 0.7 when evaluated using data including previously learned participants. However, the estimation accuracy decreased for unseen participants. This result indicates substantial inter-individual variability in facial-expression responses to thermal discomfort. These results suggest that ECG-derived physiological features and facial-expression-based affective features provide complementary information for thermal comfort estimation. These findings demonstrate the feasibility of occupant-centered thermal comfort estimation using physiological and facial-expression features, while highlighting the importance of personalization for practical vehicle applications.

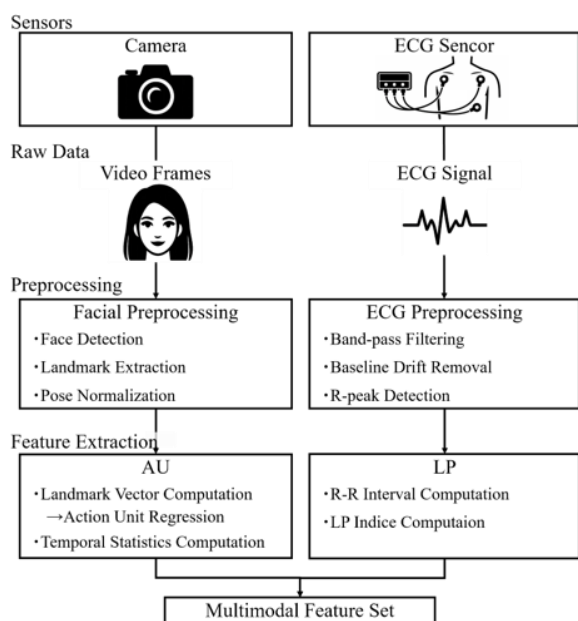


Fig.2 Multimodal Thermal Comfort Estimation System.

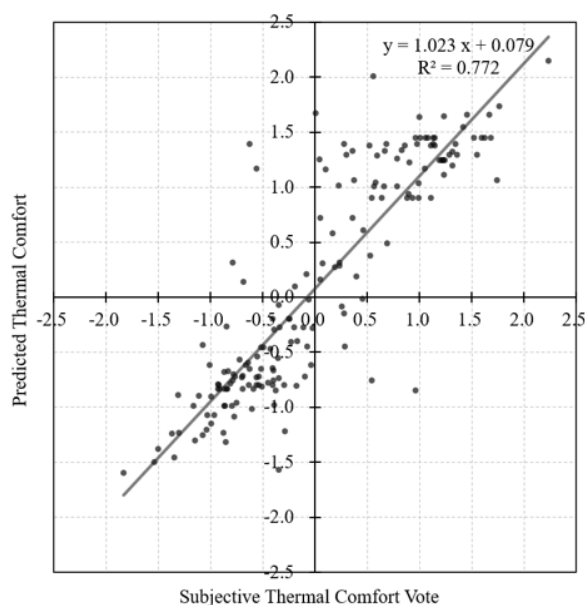


Fig.2 Validation Results of Thermal Comfort Estimation.