sensors

MDPI

*Article*

# DRER: Deep Learning–Based Driver's Real Emotion Recognizer

**Geesung Oh [1], Junghwan Ryu [1], Euiseok Jeong [1], Ji Hyun Yang [2], Sungwook Hwang [3], Sangho Lee [3] and Sejoon Lim [2,*]**

[1] Graduate School of Automotive Engineering, Kookmin University, 77, Jeongneung-ro, Seongbuk-gu, Seoul 02707, Korea; gsethan17@kookmin.ac.kr (G.O.); jhryu1003@kookmin.ac.kr (J.R.); euiseok_jeong@kookmin.ac.kr (E.J.)
[2] Department of Automobile and IT Convergence, Kookmin University, 77, Jeongneung-ro, Seongbuk-gu, Seoul 02707, Korea; yangjh@kookmin.ac.kr
[3] Chassis System Control Research Lab, Hyundai Motor Group, Hwaseong 18280, Korea; gazz@hyundai.com (S.H.); imprince@hyundai.com (S.L.)
* Correspondence: lim@kookmin.ac.kr; Tel.: +82-2-910-5469

**Abstract:** In intelligent vehicles, it is essential to monitor the driver's condition; however, recognizing the driver's emotional state is one of the most challenging and important tasks. Most previous studies focused on facial expression recognition to monitor the driver's emotional state. However, while driving, many factors are preventing the drivers from revealing the emotions on their faces. To address this problem, we propose a deep learning-based driver's real emotion recognizer (DRER), which is a deep learning-based algorithm to recognize the drivers' real emotions that cannot be completely identified based on their facial expressions. The proposed algorithm comprises of two models: (i) facial expression recognition model, which refers to the state-of-the-art convolutional neural network structure; and (ii) sensor fusion emotion recognition model, which fuses the recognized state of facial expressions with electrodermal activity, a bio-physiological signal representing electrical characteristics of the skin, in recognizing even the driver's real emotional state. Hence, we categorized the driver's emotion and conducted human-in-the-loop experiments to acquire the data. Experimental results show that the proposed fusing approach achieves 114% increase in accuracy compared to using only the facial expressions and 146% increase in accuracy compare to using only the electrodermal activity. In conclusion, our proposed method achieves 86.8% recognition accuracy in recognizing the driver's induced emotion while driving situation.

**Keywords:** human–machine interface; emotion recognition; real emotion; driver's emotional state; deep learning; sensor fusion



**Citation:** Oh, G.; Ryu, J.; Jeong, E.; Yang, J.H.; Hwang, S.; Lee, S.; Lim, S. DRER: Deep Learning–Based Driver's Real Emotion Recognizer. *Sensors* **2021**, *21*, 2166. https://doi.org/10.3390/s21062166

Academic Editor: Mario Munoz-Organero

Received: 1 February 2021
Accepted: 16 March 2021
Published: 19 March 2021



## 1. Introduction

Drivers' emotional state affects their ability to drive [1,2]. As vehicles become more intelligent, it becomes increasingly important to recognize the driver's emotions. Accurately detecting the driver's emotional state allows the vehicle to respond more quickly to the driver's emotional needs; it can provide adequate infotainment support and adjusts vehicle dynamics for a safer and more comfortable ride. In intelligent vehicles, recognizing the driver's emotion is emphasized because vehicles can select the options according to driver's emotional state (e.g., driving mode, song to change the atmosphere and driving by themselves).

In the human–machine interface, facial expressions are considered important because they are useful for revealing emotions between people. These methods based on facial expressions have been established as a research field called facial expression recognition (FER). With the great development of deep learning-based image recognition technology, deep learning is more utilized for FER [3–8]. However, facial expressions cannot always reveal human's real emotions due to various factors. Particularly, this characteristic is even more significant in case of drivers. For instance, when a driver frowns while driving,