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路怒识别与实时监测：技术进展与挑战

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摘　要

"路怒"会显著影响驾驶表现、增加交通事故风险。为了有效预防路怒的发生，研究人员已经开发出多种技术和方法尝试对路怒情绪进行准确识别和实时监测，这包括路怒特质与倾向测量、路怒状态的监测以及情感计算技术的应用。目前的监测技术已有长足发展，但仍存在一些局限和挑战，未来的研究需要综合利用个人特征和情景数据，并增加车内因素的权重分析。

关键词

驾驶情绪，多模态，特质测量，情感计算，状态监测

Road Rage Identification and Real-Time Monitoring: Technological Advances and Challenges

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Abstract

Road rage can significantly affect driving performance and increase the risk of traffic accidents. To effectively prevent the occurrence of road rage, researchers have developed various technologies and methods to accurately identify and monitor road rage emotions in real time, including the measurement of road rage traits and tendencies, monitoring of road rage states, and the application of affective computing technology. The current monitoring technology has made great progress, but there are still some limitations and challenges. Future research needs to comprehensively utilize personal characteristics and situational data, and increase the weight analysis of

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in-vehicle factors.

Keywords

Driving Emotions, Multimodal, Trait Measurement, Affective Computing, State Monitoring

1. 引言

“路怒(Road rage)”通常被定义为对其他驾驶者的敌对行为，包括但不限于尾随、言语辱骂等(Shinar, 1998)。也有研究者将路怒的范围限制得更为狭窄，认为它仅指那些更为极端的、可能导致直接对抗的攻击性或威胁行为，例如故意撞击他人车辆、下车发生肢体冲突等(Wells-Parker et al., 2002)。路怒会伴随有驾驶者的不良情绪(Braun et al., 2019; Deffenbacher et al., 2007; Zimasa et al., 2017)，交通中的一些压力情境(例如交通拥堵)是激发路怒情绪的催化剂(Löcken et al., 2017; Ota et al., 2024)，这些负面情绪会显著影响警觉性和决策能力，因此，在驾驶中实时监测驾驶者的不良情绪并及时调节对预防交通风险至关重要。

早期研究强调，具有某些特定人格特质的个体似乎更倾向于表现出路怒情绪(Bogdan et al., 2016; Deffenbacher et al., 2001a, 2001b; Wickens et al., 2011)，但是，随后的研究表明，个体的驾驶行为同样受到环境因素的影响，例如交通拥堵或其他驾驶压力情境可能引发的挫折感(Löcken et al., 2017; Ota et al., 2024)。相应地，路怒的测量技术从最初的基于个性特质的量表评估，发展到对驾驶时实时情绪状态的监测。本文将对此进行介绍。

2. 路怒特质与倾向测量

个人特质与路怒现象之间存在着密切联系，特质不仅塑造了个体的驾驶行为和情绪反应模式，而且在驾驶情境中，它们还对个体的愤怒情绪的产生和表达起着决定性作用。

2.1. 个体愤怒特质的测量

早期研究中，研究者采用了已有的愤怒特质量表来直接测量路怒。他们基于一个核心假设：即一般性的愤怒测量工具能够有效预测个体在驾驶过程中的路怒行为。这种方法简化了研究过程，并为理解路怒情绪提供了一个初步的量化手段。

特质愤怒是指个体倾向于体验愤怒的稳定人格维度，表现为更频繁和更强烈地体验愤怒情绪(Spielberger et al., 1988)。拥有高特质愤怒的个体，不仅在其日常生活情境中表现出较强的攻击性行为倾向，同样在面对交通出行情景时，也会更频繁地产生愤怒情绪，并更有可能展现出明显的攻击性驾驶行为(Bogdan et al., 2016; Deffenbacher et al., 2001a, 2001b; Ge et al., 2017; Wang et al., 2024)。一般使用特质愤怒量表(Trait Anger Scale, TAS)、状态–特质愤怒表达量表(State-Trait Anger Expression Inventory, STAXI)进行测量(Bogdan et al., 2016; Wang et al., 2024)。

除了愤怒特质外，具有A型人格、高冲动特质、自恋特质的个体在驾驶行为中也表现出更高的竞争性和冒险倾向(Feng et al., 2016, 2017; 王晓昧，2022)，同时伴随情绪控制能力减弱(Ball et al., 2018; Kovácsová et al., 2016)、过度自我中心以及对自身优越感与特权感的固执认知(Hennessy, 2016; Mithen et al.,

2023)，更容易产生路怒。一般采用 A 型行为模式量表(Type A Behavior Pattern Scale)、UPPS 冲动性量表、Go-NoGo 范式、自恋人格量表(Narcissistic Personality Inventory, NPI)对这些特质进行测量(Bresin, 2019; Feng et al., 2017; Hennessy, 2016; Mithen et al., 2023; Šašinka et al., 2023; 王晓昧，2022)。

2.2. 经典路怒量表

研究者逐渐意识到，路怒不仅仅是一般性愤怒的简单延伸，它在驾驶环境下还有着独特的触发因素和表现形式，因此有必要开发专门针对路怒行为的量表。

Deffenbacher 等人(1994)开发了驾驶愤怒量表(Driving Anger Scale, DAS)，包含无礼行为、交通阻碍、敌意手势、缓慢驾驶、警察在场、非法驾驶 6 个维度。该量表可以精准衡量驾驶员面对各种交通诱发情境时可能出现的愤怒反应特征(Deffenbacher et al., 2016)。DAS 在多个国家的不同驾驶员样本中得到了有效的验证(Balzarotti et al., 2023; Brandenburg & Oehl, 2021; Cong et al., 2021; Deffenbacher et al., 2001a; Matović et al., 2020; Stephens et al., 2016; Trung Bui et al., 2022; Wang et al., 2024; Zhou et al., 2022b)。这证明了 DAS 作为衡量驾驶情境下愤怒情绪普适性工具，具有可靠性和跨文化的适应性。驾驶愤怒倾向量表(Propensity for Angry Driving Scale, PADS)模拟了道路上可能遭遇的各种情境，并配以四个反映个体潜在行为反应的选择项，旨在揭示和预测驾驶人在面对此类情况时可能出现的愤怒驾驶或攻击性驾驶行为(DePasquale et al., 2001)。研究表明，PADS 量表在预测交通事故的发生、攻击性驾驶行为及高风险驾驶行为方面具有显著的价值，并与 DAS 相比具有一些优势，如在预测违规驾驶事件上表现出更高的准确性(Dahlen & Ragan, 2004)。PADS 和 DAS 可以作为互补的工具，用于评估攻击性驾驶。

为进一步研究驾驶者愤怒表达的典型方式，Deffenbacher 等人(2002, 2007)开发了驾驶愤怒表达量表(Driving Anger Expression Inventory, DAX)，包含言语攻击、身体攻击、使用车辆来表达愤怒、合理表达情绪 4 个维度。该量表包含了两大类驾驶愤怒表达方式：一是适应性/建设性表达，指的是通过诸如主动避让激怒自己的驾驶员、进行放松活动缓解愤怒、以及运用认知技巧调整对冲突事件的理解，以确保安全驾驶和冷静应对问题；另一类是攻击性表达，涵盖言语、身体及车辆操作三个方面的愤怒表现。DAX 作为评估驾驶愤怒表达的有效工具，在多文化中得到了验证。该量表可以有效揭示性别、文化背景、驾驶经验等因素在愤怒表达上的差异(Brandenburg et al., 2017, 2019; Cong et al., 2021; Deffenbacher et al., 2001a, 2004, 2007; Herrero-Fernández, 2011; Öztürk et al., 2021; Sârbescu, 2012; Villieux & Delhomme, 2010; Zhou et al., 2022b)。

综上，目前已有多个路怒量表得到了认可，在预测交通事故、路怒行为等方面显示出良好的应用价值，但也有研究者指出，目前的量表尚无法完全涵盖所有与路怒相关的复杂因素(Dahlen & Ragan, 2004; DePasquale et al., 2001; Zhou et al., 2022b; 顾雯婧，2022)。此外，尽管量表在发展过程中已能够不仅测量个体的特质愤怒，也能评估其状态愤怒，但这种方法仍然存在明显的局限性。自我报告往往带有主观性，研究发现，社会期望偏差与愤怒程度评分之间存在显著的负相关(Zepf et al., 2021)。个体对社会认同的需求越强烈，他们在自我报告中描述的愤怒情绪的频率、持续时间和强度越低(Fernandez et al., 2019; Wang et al., 2024)。同时，实时自我报告可能会干扰驾驶员的注意力，影响其驾驶表现；而事后通过观看视频进行的自我报告则可能受到记忆偏差的影响(Zhou et al., 2022a)。

3. 路怒状态的监测

欧盟(European Union, EU)宣布，从 2025 年起，新注册的车辆将强制安装驾驶员监控系统，以保障驾驶安全性。路怒现象常常伴随愤怒情绪的产生，因此，在驾驶情景中监测愤怒情绪状态也是一种识别路怒的有效方法。情绪状态的变化通常会伴随着生理变化，如心率、呼吸、血压等，通过测量这些生理指

标可以判断个体的情绪状态(Aruna Gladys & Vetriselvi, 2023; Dzedzickis et al., 2020)。目前生理信号采集较为便携和容易，已在真实驾驶情景中使用。

3.1. 心率(Heart Rate, HR)和心率变异性(Heart Rate Variability, HRV)指标的监测

HR 和 HRV 是反映自主神经系统活动的关键指标，与情绪状态紧密相关(Guo et al., 2016; Rakshit et al., 2016; Rumpa et al., 2021; Q. Zhang et al., 2024; Zhu et al., 2019)，一般通过心电图(Electrocardiogram, ECG)和光电容积脉搏波(Photoplethysmography, PPG)技术测量。

在驾驶情景下，HR 与 HRV 作为一种客观生理指标，已得到广泛应用(Braun et al., 2021; Habibifar & Salmanzadeh, 2022a; Hidalgo-Muñoz et al., 2019; Lu et al., 2022; Persson et al., 2021; Zhang et al., 2024)。Minhad 等人(2017)通过记录驾驶者在面对不同情绪刺激时的 ECG 信号，发现通过特定的 HRV 特征能够以高准确率区分愤怒情绪。Wang 等人(2023)提出了一种 HRV 特征挖掘方法，通过幅度级量化技术和逻辑回归分类算法，对包括愤怒在内的 17 种复杂情绪进行识别，识别率达到 84.3%。Habibifar 和 Salmanzadeh (2022a)通过分析 HR、HRV 等指标结合机器学习模型，对驾驶者在模拟驾驶环境中的负面情绪状态监测的准确性达到了 88%。此外，HR 和 HRV 还可以作为评估驾驶者认知负荷的生理指标，其中 HR 通常随着认知负荷的增加而升高，而 HRV 则可能随之降低(Gabaude et al., 2012; Loeches De La Fuente et al., 2019)。近红外相机技术可以通过提取心率信息来监测驾驶员的生理状态，显示出在复杂光照环境下的优势(Xu et al., 2023; Zhang et al., 2018)。

3.2. 皮电活动(Electrodermal Activity, EDA)的监测

情绪刺激还会引起汗腺活动和皮肤电导率提高，EDA 是一种基于皮肤电活动的变化来推断个体的情绪状态的生理方法。皮肤电水平(Skin Conductance Level, SCL)反映了基础生理唤醒状态，能有效评估驾驶员的唤醒度(Li et al., 2022a)。Loeches De La Fuente 等人(2019)发现，驾驶中的认知负荷增加往往伴随着 SCL 的提高，而放松则与低 SCL 相关。皮肤电反应(Skin Conductance Response, SCR)是与情绪事件相关的电导率的快速变化，SCR 的增加通常与负面情绪刺激有关(Habibifar & Salmanzadeh, 2022a, 2022b; Hieida et al., 2023)，愤怒作为一种高唤醒度、负面愉悦度的情绪，被认为与高 SCR 相关(Lee et al., 2023)。Zontone 等人(2020)指出，在驾驶中由于移动、振动等会产生运动伪影，需要使用算法识别并去除这些运动伪影以提高 EDA 的识别可靠性。通过对 EDA 平均值和标准差等特征的分析，对驾驶负面情绪识别的准确率可达 90% (Habibifar & Salmanzadeh, 2022a)。功能性红外热成像技术可以通过分析面部热变化识别情绪唤醒和愉悦度，这种方法被认为是传统 EDA 的可靠替代品(Kosonogov et al., 2017)。此外，结合 EDA 和面部热成像的方法也被提出，用于评估用户对视觉刺激的情绪反应(Jukiewicz et al., 2021)。

3.3. 呼吸信号(Respiratory, RESP)的监测

情绪状态的改变会直接影响个体的呼吸模式，通过监测个体的 RESP 特征，可对当前情绪状态进行推断(Ayata et al., 2020; Gouveia et al., 2024; Hameed et al., 2019; Hassib et al., 2019; Hirabayashi & Iwamoto, 2019; Khan et al., 2021; Li et al., 2023; Oh et al., 2020; Siddiqui et al., 2021; Zhang et al., 2017)。个体处于心理放松与情绪平静的状态时，其呼吸行为呈现显著的深度化与节律放缓特征(Katsis et al., 2008)；而在愤怒状态时，则会出现呼吸急促的现象(Zhang et al., 2017)。Zhang 等人(2017)通过稀疏自编码器，仅提取 RESP 特征，使用逻辑回归模型对情绪唤醒度及效价进行了有效分类。驾驶中一般利用脉冲雷达捕捉呼吸信号，通过机器学习算法，实现无需身体接触的情绪识别，为监测路怒提供了一种新的非侵入式方法(Siddiqui et al., 2021; Zheng et al., 2020)。

3.4. 血压信息的监测

血压的变化不仅与个体的生理状态有关，还可能与情绪反应和风险行为相关联(Kim et al., 2020; McCubbin et al., 2020)。McCubbin 等人(2020)在模拟驾驶实验中发现，较高的静息舒张压与风险驾驶行为有显著关联，表现为更快的车速以及更激进的尾随行为，这可能反映了血压相关的情绪抑制对威胁评估和风险回避动机的影响。Kim 等人(2020)使用 EEG、脉搏和血压数据构成了驾驶压力指标，成功使用支持向量机对情绪状态进行了分类，帮助判断驾驶者情绪状态是否稳定。Arakawa 等人(2022)提出一种非接触式血压监测系统，可以通过发射红外光并分析皮肤反射回来的光信号变化，采用光体积描记术原理和变点方法算法，连续估算和监测血压变化。在驾驶情境中，这种非接触式的测量方法不会干扰驾驶者的操作或姿势，对于评估驾驶情绪状态具有潜在的应用价值。

综上，目前利用可穿戴设备及非接触式监测技术通过多种生理指标，能够较好地识别驾驶中的愤怒情绪。然而，在将这些监测技术应用于实际驾驶场景时，仍面临一些挑战，例如监测设备的高昂成本、专业技术的维护需求、用户对监测系统的接受程度、传感器的精确度与稳定性，以及监测数据的即时分析处理等问题(Arakawa et al., 2022; Du et al., 2022; Gouveia et al., 2024; Xu et al., 2023; Zhang et al., 2018)。

4. 情感计算技术的应用

随着情感计算领域的兴起，许多与情绪识别相关的计算机技术，如面部情绪识别、语音情绪识别等在现实中已广泛运用。这些非接触式技术在提高驾驶安全性和识别驾驶员情绪状态方面具有重要潜力，尤其是在需要实时、准确评估情绪以做出快速反应的场景中。

4.1. 面部情绪识别(Facial Emotion Recognition, FER)

面部表情是观察、分辨情绪的重要指标。愤怒作为一种强烈的情绪体验，通常伴随着面部肌肉紧张、皱眉、面色变红等特征，同时还会出现诸如咬牙、咬肌等特有的动作变化(Dong et al., 2022)。FER 是通过采用包含面部情感信息的图像或视频数据来实现情绪识别的技术(Sariyanidi et al., 2015)。FER 在对面部进行预处理，剔除干扰因素后，精确提取如睁眼度、眉眼距离比、嘴部闭合比等面部特征点定位(Shulei et al., 2022)，经过机器学习、深度学习算法训练，能够对驾驶中愤怒、恐惧、悲伤等基本情绪进行准确识别(Jeong et al., 2020; Leone et al., 2021; Li et al., 2022b; Luan et al., 2024; Shang et al., 2022; 夏王浩，2023)。Du 等人(2022)通过 Kinect 设备捕捉面部视频并使用卷积神经网络和双向长短期记忆−条件随机场来提取面色和心率特征，在检测愤怒、抑郁等情绪时正确率超过 80%。

目前 FER 已经被用于实时监测驾驶员的情绪状态，实现了在出现可能影响行车安全的负面情绪时调节技术的及时介入(Li et al., 2022b; Saadi et al., 2024)。例如，凯迪拉克的 SUPER CRUISE 超级辅助驾驶系统可以利用微摄像头以及红外传感器实时追踪驾驶者面部表情及视线；捷豹路虎开发的情绪探测及舒缓系统可以通过识别驾驶者面部情绪自动调整驾驶环境。近年来，为进一步提高识别效率，研究者将 FER 与一些生理指标相结合，如 EDA、RESP、HR 等，其识别准确率得以有效提升(Khan et al., 2021; Oh et al., 2021)。

4.2. 语音情绪识别(Speech Emotion Recognition, SER)

语音同样是传递情绪的关键途径，它能够通过音高、音量和语速的变化来反映个体的情绪状态(Aruna Gladys & Vetriselvi, 2023; Davis et al., 2020)。愤怒语音有其独特的声学特征，如更高的基频和更快的节奏、音高变化、声门不对称性等(Kadiri et al., 2020; Kapoor & Kumar, 2022)。SER 通过处理和理解各种语音信号来检测输入的情绪(Lee & Narayanan, 2005)。在驾驶中通过提取驾驶者语音的音高周期、能量、共振峰、

梅尔频率倒谱系数等特征，可以有效对情绪进行分类(Ahuja & Shabani, 2023; Wu et al., 2022)。Requardt等人(2020)通过分析真实驾驶场景中的音频记录，开发了一种机器学习分类器，能够有效识别驾驶员的挫败情绪。Wu 等人(2022)构建了一个融合变换器网络和卷积神经网络的 SER 系统，显著提高了对驾驶愤怒情绪的识别精度。将 SER 与生理信号、FER 结合使用，识别准确率也能得到有效提升(Hieida et al., 2023; Oh et al., 2022; Prasada Rao et al., 2019; Ying et al., 2024; Zhou et al., 2023)。

4.3. 驾驶行为的监测

除了直接监测驾驶员的愤怒情绪，一些研究者还通过监测驾驶行为来间接评估驾驶员的情绪状态，这种方法可以提供关于驾驶员情绪变化的额外信息。美国汽车工程师学会(Society of Automotive Engineers, SAE)将纵向控制(如车头距离、碰撞时间)以及横向控制(如车道位置标准偏差、车道偏离)视为驾驶表现的衡量标准(Braun et al., 2021)。鉴于情绪能够影响驾驶表现，有研究者将驾驶表现的降低，或是危险驾驶表现的增多，如更倾向于加速、闯黄灯、紧急制动等(Zhang et al., 2016)，视为路怒的行为表现(Braun et al., 2019; Jeon et al., 2015; Zhang et al., 2016)。所以除了驾驶者的生理数据外，还可以结合如方向盘、油门踏板和刹车踏板等车辆操作数据、驾驶者行为数据乃至车道数量、与前车的距离、天气条件等驾驶环境因素对驾驶者的情绪状态进行有效识别。

5. 未来研究展望

综上所述，监测驾驶中的路怒情绪对于预防负面驾驶行为至关重要。路怒情绪是驾驶员的个人特质与环境因素的复杂交互结果，体现了心理学中“先天与后天”的争议。但当前的最新技术却多聚焦于环境因素对路怒情绪的影响，忽视了个体差异，未认识到两者的交互重要性。

大量研究已经发现个体特质与路怒症之间存在密切的联系(Bogdan et al., 2016; Deffenbacher et al., 2001a, 2001b; Wickens et al., 2011)，但目前路怒的实时监测系统还很少将驾驶者的个人特质、情绪状态以及驾驶情景(如交通状况、车辆状态、路面信息等)有效结合起来。通过梳理近三年我国在路怒监测与调节领域的有效专利(见表 1)可以发现，除了先前研究涉及的监测手段，专利中还提出了一些新的监测技术，例如使用方向盘上的压力传感器通过驾驶者抓握方向盘的压力大小来反应其愤怒程度(任振轩等，2022；吕志强，2022)，但这些技术还是集中于监测驾驶过程中的愤怒情绪及其行为表现。目前仅有林泽蓬等人(2022)的专利尝试将驾驶者的性格特征纳入了情绪识别算法中，主要方法是通过性格测试将性格信息预先存入数据库，通过面部识别驾驶者身份以匹配性格库中的数据，作为情绪识别算法的一个输入参数，辅助计算愤怒水平值，输出相应的驾驶调控策略。

Table 1. Effective patents on road rage monitoring in China in the last three years
表 1. 近三年我国路怒监测相关有效专利

发明人	面部识别	语音识别	HR/HRV	血压	车辆数据	肢体动作	其他
王晓栋等，2024					√		
丁同强等，2024					√		
臧珂欣等，2024	√	√				√	
陈仪权等，2024	√	√	√	√			EDA
柳欣等，2024	√	√					
徐云和等，2023					√		
徐婷婷，2023		√					

续表

徐新民等，2023	√	√					
郑宏宇等，2023	√						
杜广龙，2023	√		√				
张晋东等，2023	√						
梁颖等，2023	√						
坂大弘幸，2023					√		
杨文轩，余天俊，2022			√				
柳佳妮，赵国朕，2022	√		√				脑电、肌电
法提赫•波里克利等，2022	√	√	√	√	√	√	体温
杨立才，张成昱，2022	√						呼吸信号
胡旭，2022	√	√			√		
林泽蓬等，2022	√		√				性格
吕志强，2022	√		√	√	√		血氧、方向盘压力
孙晓，汪萌，2022	√		√			√	
任振轩等，2022	√	√					方向盘压力
袁伟等，2021					√		
梁新强等，2021	√		√	√	√		血氧

此外，除了交通拥堵和他人驾驶行为等外部因素之外，车内因素——例如与乘客的争执或不适宜的车内环境——同样能够诱发路怒情绪(Hu et al., 2012; Nakagawa & Park, 2014; Smart & Mann, 2002; Ye et al., 2023)。这些发现说明，在路怒监测和评估模型中，必须对车内因素赋予适当的权重。

基于上述分析，路怒是个人特质和情景诱发因素共同作用的结果，因此一个理想的综合监测模型应该能够全面分析来自多个源头的信息，整合个人特质数据和实时驾驶情景数据。该系统应具备以下几个核心能力：1) 生理信号的采集：确保数据采集的连续性和精确度，同时保证驾驶者的舒适度和安全性；2) 个人数据库的建立：通过驾驶前的问卷调查、日常驾驶行为分析等建立驾驶者个人数据库，利用算法实现为每位驾驶者定制个性化风险预测模型；3) 车外路况的监测：利用 GPS、车外激光雷达、摄像头等对路况进行监测，实时评估外部环境对驾驶者情绪的影响，准确识别易引发驾驶者路怒的特定场景；4) 车内环境及行为监测：对车内环境(如温度、噪声等)、驾驶者及乘客行为进行检测，识别可能引起冲突的行为模式。最后，监测系统应与路怒的调节手段相结合，建立闭环反馈机制，一旦监测到路怒的发生倾向，系统应立即启动干预措施。由此形成一套全方位、个性化的预防路怒解决方案，保障驾驶安全。

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