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认知车——结合认知科学和控制理论的新研究方向

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摘要: 本文首先介绍了当前"认知车"研究的内涵和外延及其与智能汽车研究的关系, 着重回顾了目前的驾驶员刺激–反应过程、决策–动作过程的建模方法和应用成果. 其次, 本文概述了环境认知和驾驶员认知, 驾驶员行为评估和面向驾驶员的控制之间的联系, 指出了相关的研究难点并展望了今后的研究热点. 最后, 本文突出了人在控制系统中的作用, 讨论了如何从"认知车"的角度出发将认知科学和控制理论结合.

关键词: 智能汽车; 认知车; 认知科学; 先进控制

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Cognitive vehicle: a new research direction integrating cognitive science and control theory

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Abstract: The concepts and contents of the research on the "cognitive car" and its relationship to the "intelligent vehicle" are explained. Recent important research results on stimula-response and decision action modeling and their applications are reviewed. The relationship between the environment recognition and the driver recognition, the links between the driver decision evaluation and the driver-oriented controller design are discussed, respectively. Some unsolved difficult problems and future hot topics are also presented. Finally, the integration of cognitive science and control theory on the basis of intelligent vehicles is highlighted, with a special emphasis on the human-in-loop control systems.

Key words: intelligent vehicle; cognitive vehicle; cognitive science; advanced control

1　引言(Introduction)

近年来, 为了缓解日益增长的交通压力和减少交通事故, 智能交通系统和智能汽车(intelligent vehicles)技术得到了来自政府、交通业界和科研院所的广泛重视. 其核心就是利用智能信息技术, 使得"人–车–路"之间能够构成更加和谐统一的系统[1,2].

最近, 一些国内外研究者提出了所谓"认知车"(cognitive car)的概念, 强调应更多的开展对驾驶员的研究.

顾名思义, "认知车"乃是认知科学(cognitive science)的一个研究载体和应用实例. 简而言之, 认知科学是关于人类心智(意愿)和智能(intelligence)跨学科的研究, 涵盖哲学、心理学(psychology)、人工智能(artificial intelligence)、神经科学(neuroscience)、行为科学(behaviour science)、语言学等诸多方面. "认知车"主要是分析驾驶员的心理和行为之间的因果联系, 试图从人工智能和神经科学的角度进行解释并开发出相应的驾驶员意图分析和判断的软件, 以检测驾驶员错误行为或辅助驾驶汽车, 减轻驾驶员的负担.

众所周知, 目前智能汽车的研究分为全主动驾驶(fully autonomous driving)和辅助驾驶(driver assistance)两大方向. 前者主要是用于军事科研等特殊场合, 而后者主要是面向广大普通汽车用户. 为了合理地进行辅助驾驶, 显然需要正确的"认知"驾驶员的行为. 因此, "认知车"和辅助驾驶系统的研究关系密切.

一般而言, 驾驶员的基本工作(task, function)分为4个层次[3~6]:

1) 中长期计划行为(planned behaviour);

2) 在1)的基础上接受短期的外部信号刺激

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(contemporary stimuli);

3) 根据1)中产生的计划和2)中接收到的外部刺激产生相应的短期动作指令(response, decision);

4) 实施这些动作指令(action). 参见图1.

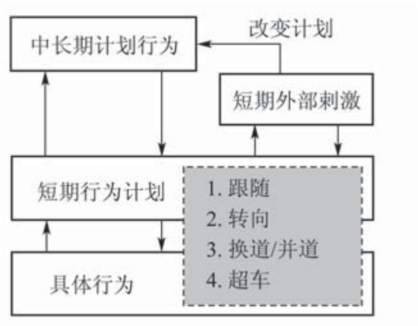

图 1 驾驶工作的层次图

Fig. 1 Hierarchy of driver's tasks

从目前的研究来看, 关于驾驶员行为的相关研究大致集中于如何观测、理解和建模3个递进的人类思维行动过程:

1) 刺激–反应过程(stimuli-response): 偏重驾驶员的心理(psychology modelling), 从心理学描述驾驶员短期行为变化的内在因素;

2) 反应–决策过程(response-decision): 主要研究驾驶员的中长期计划行为和短期动作之间的区别和联系, 考虑不同驾驶员的心理特质对决策的影响;

3) 决策–动作过程(decision-action): 主要是驾驶员的行为建模[6](behaviour modelling), 从生理建模(physiological modelling)的角度解释驾驶员意愿和具体行为之间的转换过程.

其中的反应–决策过程迄今已有诸多的成果[7~10]. 例如如何界定冲动驾驶(aggressive driving)和冲动驾驶对交通流和交通安全的影响等等. 但这部分研究通常不涉及驾驶员行为的在线认知和识别. 因此, 通常不视为"认知车"研究的一部分.

本文拟按此刺激–反应和决策–动作这两个和"认知车"互相密切的方向, 分别对相关研究进行分析, 并在最后讨论今后的发展方向.

2 刺激–反应过程建模(Stimuli-response process modeling)

为了分析驾驶员对外界刺激的生理、心理反应, 首先需要分别采集外部刺激信号和驾驶员的内在反应信号. 这也大致符合研究者对于智能汽车研究对认知任务的一般划分: 向外认知(环境认知[11])和向内认知(驾驶员认知[6])两个方向.

2.1 环境认知(Environment cognition)

环境认知基本任务主要是确定车辆运行的环境, 一般包括:

a) 道路/车道认知(road/lane recognition)[12];

b) 交通灯和交通标志认知(traffic lights/signs recognition);

c) 障碍物认知(obstacles recognition): 包括车辆[13]、行人[14]、自行车等运动着的其他交通参与者和安全锥、石块等静止的纯粹障碍物[8].

其中前两者又被合称为交通设施认知(traffic infrastructure recognition); 而后者又多集中于交通参与者认知(traffic participator recognition).

而现在, 交通场景的高级认知任务也正被越来越多的研究者所重视. 其中包括事故认知、天气认知等. 相关研究表明, 这些因素也会对驾驶员的心理产生影响. 但具体如何定量描述这些影响还需要更加深入的讨论.

正确的实现环境认知是"认知车"的研究基础. 目前已有较多研究综述[6,11~16], 此处不再赘述.

2.2 驾驶员认知(Driver cognition)

驾驶员认知主要是确定驾驶员状态和正在进行的动作. 与刺激–反应过程建模相关的主要是: 驾驶者的视线、表情和动作等等.

随着图像识别技术的发展, 目前已经可以较好的将驾驶员所注视的景物和所进行的动作结合起来理解环境刺激是如何导致驾驶员的行为的[17~19]. 例如, 现在的图像识别技术能实时捕捉驾驶员瞳孔的朝向, 可进一步籍此判断驾驶员正在观察什么物体.

但是这方面的研究目前还存在不小的困难, 特别是:

a) 驾驶员行为和眼神的视频监控受环境光照变化影响较大, 有时不能提供足够清晰的图像以供判读;

b) 与其他信息结合不够, 有时仅凭图像数据不能较好的判断驾驶员的生理心理反应.

这些都需要进一步的探索.

2.3 心理/生理建模(Physiological psychology modeling)

将驾驶员的视线与行为信息(如方向盘转向、握力等数据)与道路环境信息联系起来, 就能尝试解释驾驶员的短期行为是如何产生的.

例如依次记录到:

i) t_1时刻路面出现减速牌;

ii) t_2时刻驾驶员的视线扫过减速牌, 也即驾驶员看到减速牌;

iii) t_3时刻驾驶员开始刹车.

那么就可以由此推测出驾驶员对减速牌这一外界刺激产生反应的时间差, 确认减速牌对驾驶员的心理影响程度.

但是, 如何才能真实客观的描述驾驶员的动机(motivation)依然是困难的. 这是因为:

1) 实际上, 不能生硬地将stimuli-response, decision-action这两者割裂开来研究. 因为, 往往需要进一步考察驾驶员的行为来判断其到底产生了何种心理变化. 但很多情况下, 驾驶员最终没有产生相应的动作, 或者原来的反应被新的刺激信号打断, 使得难以轻易获得可以确信无误的数据.

2) 目前尚缺乏可信的准确定量的人类思维活动的数学模型. 因此, 研究中往往借助已有的人工智能模型进行类比推理, 包括人工神经网络(artificial neural networks)[20]、Bayesian模型(Bayesian models)[21]. 但这些比拟模型往往过于简化, 且不一定符合驾驶员的真实决策过程. 例如目前采用的Bayesian模型往往是离线训练后不再改动, 难以满足在线实时调整决策策略的要求.

3) 人脑同时处理多种信息, 难以确定到底是什么信息引起了相关的动作. 目前只能研究少量特定外界刺激的影响, 但这些信息已然非常有用.

4) 同时驾驶员的内在生理、心理基础也决定了对于外界刺激反应的不同[22~29]. 比如, 疲劳(fatigue)、强烈的情绪和感觉(emotion and feeling)[30]等如何改变驾驶员的驾驶行为是当前的研究的热点. 因为大量的研究表明, 疲劳能让驾驶员对外界的反应变慢和不敏感[17,31]. 换而言之, 每个驾驶员在不同时刻对于外界刺激的耐受度都可能不同, 如果想要获得合理的数据, 需要进行更多的精心设计的实验, 这有助于积累足够的数据以便逐一区分各种因素的影响. 而这显然尚需更多经费和时间的投入.

驾驶员刺激–反应过程的心理/生理建模已经发展了50多年, 随着基于智能信息理论的认知技术的不断进步, 当前的相关研究正在不断深化的过程中[27]. 但如何对驾驶员正确建模尚不能在短时间之内获得满意的答案.

3 决策–动作过程建模(Response-decision modeling)

决策–动作过程的研究通常假设已经分别计算出理论上最优或者出于安全考虑必须的驾驶决策, 并判断出了驾驶员的短期意图, 而则在此基础上进一步评估驾驶员短期意图和相应动作的合理性.

3.1 驾驶员决策评估(Driver's decision evaluation)

相对于刺激–反应过程建模强调决策的来源, 决策–动作过程建模更强调决策的合理性. 一般而言, 目前的研究多是在完成环境认知之后, 产生相应的参考驾驶指令; 然后将参考驾驶指令和驾驶员的实际驾驶行为对比.

目前智能汽车研究中最为常见的驾驶员决策评估和告警子系统包括:

1) 碰撞预警(collision warning), 特别是后部撞击(rear-end collision)的预警;

2) 道路/车道偏离预警(road/lane departure warning);

3) 速度偏离预警(speed warning), 特别是结合交通标志识别;

4) 交通信号灯预警(traffic light warning);

5) 驾驶员疲劳预警(driver fatigue warning).

这5项中前4项均是基于环境认知来判断驾驶行为的合理性. 目前研究表明, 这些预警系统可在车载视觉系统和图象/视频识别系统的基础上实现, 且目前已经得到了比较好的成果. 当前研究正在向提高告警准确性, 减少误报率方向发展.

不过, 很显然, 上述这些评估任务是较为单纯和容易的. 目前对于复杂环境驾驶决策判断的研究尚非常少见. 实际上, 由于驾驶行为的复杂性, 面对同样的驾驶场景, 驾驶员可能采取非常不同的驾驶策略(strategy), 从而导致相应驾驶动作的不同; 参见图2. 这使得在设计全主动驾驶智能汽车时难以实时找到最为合理的驾驶指令. 同样, 这也使得在评估驾驶员复杂行为时遇到非常大的困难.

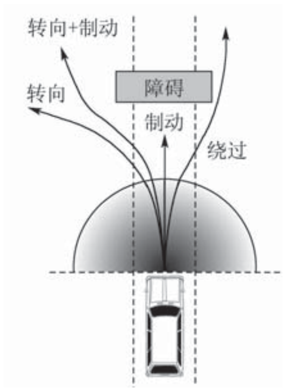

图 2 参考驾驶指令的产生

Fig. 2 Generation of referencing driving commands

如何对驾驶员地行为进行更好的理解和评估尚有待进一步的研究[32~39]. 例如, 如何更好的训练新驾驶员(driving skills training)就是一个值得深入研究的方向[40].

3.2 面向驾驶员的控制(Driver-oriented control)

在确认驾驶员驾驶决策正确之后, 还需要进一步设计面向驾驶员的控制器来帮助其更加轻松自如的完成相应驾驶动作.

目前智能汽车研究一般要求辅助驾驶系统:

a) 在必要情况下(例如侧滑), 完全接管车辆的运动控制;

b) 以不被驾驶员察觉的方式, 作为中间层插入到驾驶员输入和实际控制信号输出之间, 使得驾驶行为能变得更加合理. 这就是“认知车”研究中所

提出的面向驾驶员的控制.

目前面向要求a)的研究较多. 而最近, 面向要求b)的研究也逐渐引起了大家的研究兴趣. 其典型例子就是现在by-wire系统受到了广泛的关注. 例如已经广泛应用的steer-by-wire和brake-by-wire能识别驾驶员的动作偏好, 使得驾驶更为流畅省力. 而新型汽车的active suspension system和active camber control能让汽车做出更加高难度的驾驶动作, 增加驾驶的安全性和乐趣.

此外, 研究者正试图通过增加预控制减少安全事故的发生. 图3就展示了驾驶员的动作往往不及时或者过大过猛, 而经过预控制补偿调节后会变得及时和适度. 辅助驾驶系统在预先判断出需要进行刹车时, 通过提前1, 2 s的预减速动作同时伴随及时的刹车预警提示以避免碰撞的发生. 同时, 预控制也有助于将驾驶动作变得更为柔和, 避免驾驶员疲劳或受伤, 减少尾气噪音、减低刹车轮胎磨损.

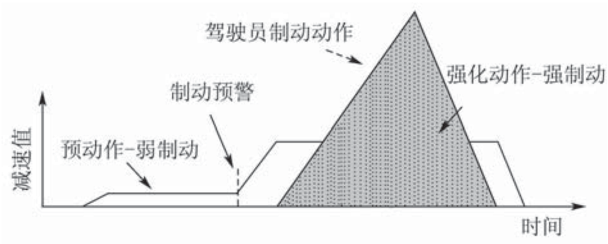

图 3 预减速动作示意图

Fig. 3 Illustration of brake in advance

但是如综述[6]中所解释的, 如何去除各种测量和执行环节引入的误差干扰[34,41]和滞后, 克服人类驾驶员的操作的不确定性和不稳定性带来的影响, 正确的理解和评估驾驶意图和相应的驾驶行为, 及时发现驾驶员的失误[42,43]依然需要更多的实测和检验.

更进一步, 还可以研究驾驶员对于所驾驶车辆动力学特性的适应性. 很显然, 相同的驾驶行为(指相同的转向力度、制动踏板力度等)作用于不同的车辆, 会产生不同的车辆动力学行为. 目前的研究均假定驾驶员已经充分熟悉了所需驾驶的车辆, 能够形成稳定的驾驶行为和对应的车辆动力学行为, 以便忽略车辆性能对驾驶员的影响, 简化研究. 这方面的研究可参见的前述分析[6].

此外, 引入控制系统造成的驾驶员行为改变[44,45]则是今后更加深入的讨论方向. 如何度量驾驶员对辅助驾驶控制系统的信任度(human trust in automation), 在辅助驾驶控制系统失效或未能达到预期控制目标时产生的惊讶(automation surprises)和反应都是值得深思的问题.

4 结语(Conclusion)

“认知车”是最近几年相关领域提出来的辅助驾驶型智能汽车设计新概念. 其基本思想是强调认知科学在智能车设计中的核心和主导地位, 从驾驶员行为认知的角度出发, 将相关研究整合在一起, 为早日将智能车推向普通市场提供动力[4].

相对于原有的智能车设计集成方式[2], 图4显示了“认知车”研究理念中以驾驶员为中心, 各部分通过驾驶员的输入(外界刺激)输出(控制行为)互相关联的特色.

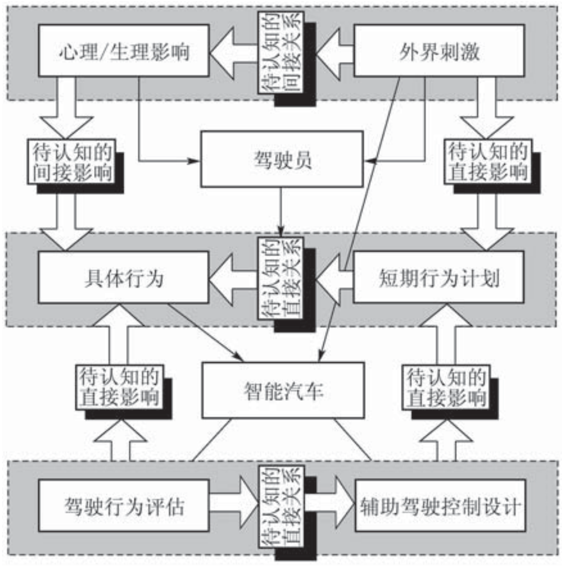

图 4 “认知车”研究框架图

Fig. 4 Framework of “cognitive car” research

因此, 不能简单的将“认知车”设计看作新瓶装老酒(old wines in new bottles). 实际上, 目前的很多控制研究中, “以人为本”(advancing technology for humanity), 考虑人在控制系统中的作用(human-in-loop effect)已成为研究的难点和热点. 而“认知车”正是将认知科学和控制领域结合起来的新兴交叉边缘学科, 有着广阔的前景.

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