A fluid-HMI approach for Haptic Steering Shared Control for the HADRIAN Project

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Abstract. Since the beginning of automated driving, researchers and automakers have embraced the idea of completely removing the driver from the Dynamic Driving Task (DDT). However, the technology is not mature enough yet, additionally social and legal acceptance issues currently represent a major impediment for reaching the commercial stage. In this sense, the European Commission has focused attention on the approach of human-centered design for the new driver role in highly automated vehicles, evaluating a safe, smooth, progressive, and reliable collaboration between driver and automation, in both authority transitions and fluid collaborative control (or Shared Control). In particular, the HADRIAN (Holistic Approach for Driver Role Integration and Automation Allocation for European Mobility Needs) project is facing this challenge. The major contribution of this work is a general framework that allows different task-collaboration between driver and automation, such as shared and traded control, considering the status of the different driving agents: driver, automation, and environment. This integration will be evaluated under the framework of fluid interfaces which represent the basic needs for achieving a safe and effective human-machine interaction in automated driving. Also, the needs and challenges of the implementation are presented to achieve a fluid interaction.

Keywords: Shared control · Autonomous vehicles · driver-automation cooperation · arbitration · partially automated vehicles.

1 Introduction

Each year more than one million people die in traffic accidents, and most of them are related to human errors, mainly driver distractions. Fully automated driving emerges as a solution by removing human error from the equation. Nonetheless, full automated driving remains unsolved for commercial vehicles due to technological, social, and legal issues. In this sense, driver-automation collaborative solutions have an increased interest around the research community, developing automated driving functionalities where both driver and automation are kept in the vehicle control loop. This modality is commonly known as Shared Control.

Shared control is a relatively new approach in the field of automated vehicles, where the researchers make use of concepts from Human-Machine Systems (HMS), that are well studied in robotics literature. Instead of switching control between humans and machines, this system allows both agents to influence actuators simultaneously with a fluid transition between them.

An important motivation for this approach is that it allows getting the best features from humans and automated operators. Machines respond quickly, excel on repetitive tasks, and can execute control signals more accurately, while humans have superior judgment, deduction, and improvisation capabilities. In Shared Control, these capabilities merge obtaining a safer system to take decisions while driving; with higher accuracy, less prone to errors, and capable of handling out of bound events.

Another way to understand Shared Control is the H-Metaphor presented by Flemisch et al. [1]. It compares the interaction between a driver and a Highly Automated Vehicle with a jockey riding a horse. Horse obeys jockey high-level commands, but they assist each other to arrive at the destination without collision. Another example is the scenario of driving lessons, where both the teacher and the student have a steering wheel and pedals working at the same time.

The development of this control modality has the attention of the European Commission, under the approach of human-centered design for the new driver role in highly automated vehicles. In particular, the HADRIAN (Holistic Approach for Driver Role Integration and Automation Allocation for European Mobility Needs) project is facing this challenge developing automated driving systems with dynamic adjustment of human-machine-interfaces that consider the environment, driver, and automation conditions.

In particular, this paper presents the approach taken for a fluid-HMI, with emphasis on the steering wheel as the haptic interface, for the development of a lateral shared controller for elderly drivers assistance systems. The structure of the article is as follows: Section II presents an overview of the HADRIAN project, Section III gives a summary on related works, Section IV explains the necessary modules for the general shared control framework, Section V mentions the challenges in the implementation of this technology, and Section VI closes with the conclusions of the work.

2 The HADRIAN Project

The European Commission has granted funding for the development of Research Innovation Actions (RIA) in the context of automated driving functionalities. HADRIAN is part of these actions, with emphasis on the human-centered design for the new driver role in highly automated vehicles. HADRIAN gathers 16 European partners that collaborate towards the implementation of future automated driving functionalities considering the driver in the transitions between AD levels. This evaluation will be performed through the implementation of three demonstrators: 1) automated passenger vehicle for elderly drivers, 2) automated driving functionalities SAE L3-4 for trucks, and 3) automated passenger vehicle for business travel. These implementations will be developed under the general HADRIAN framework (see Figure 1).

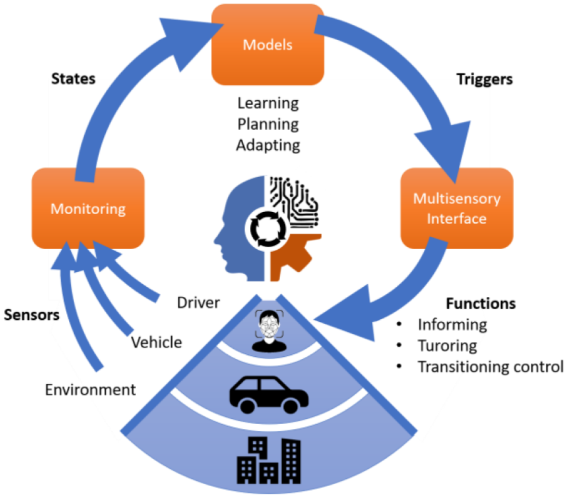

Fig. 1. HADRIAN General Driver-Automation Framework

Of these three demonstrators, the mobility need for elderly drives is the one that considers a strong interaction of the automation with the driver as an active driving agent. In this sense, the shared control approach will be implemented for this scenario. Upon this request, Tecnalia will have as the main contribution on this project the development of the fluid haptic steering shared control system that assists the elderly driver in situations where the safety is compromised, and at the same time to facilitate the driving task to reduce physical and mental workload. The specific task are described below:

1. Development of a Driver Monitoring System, in charge of getting the driver state while performing the dynamic driving task. This state indicates whether the driver can perform the maneuver safely and calculate the need for assistance. This module makes use of different sensors, data processing techniques, and fusion algorithms of multiple driver-related variables. It supplies the shared control system.
2. Implementation of Shared control system, in charge of assisting the driver at the steering wheel, with the appropriate force for guidance, maneuver avoidance, or transitions of authority for a safe, smooth, and comfortable driver-automation cooperation.

3. Implementation of separate systems, in a complete and interconnected framework to be implemented in real vehicles and specific use cases related to automated driving future applications.

These activities will be performed in collaboration with the HADRIAN consortium under a common framework that integrate different fluid-interfaces modules, which will be described in Section 4.

3 Related works

This section presents an overview of the state of the art in Shared Control applied to automated vehicles. Figure 2 gives a summary of the contributions on shared control for automated driving on the last 20 years. The positive rate of increase (both in theoretical and oriented-application contributions) is a motivation for investigating deeper into this area.

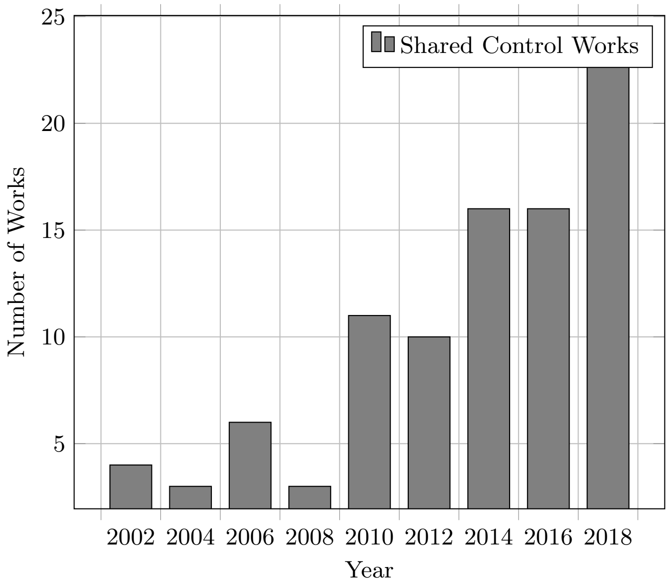

Fig. 2. Works on Shared Control in Automated Vehicles (2002-2018)

There are two general methods of vehicle control sharing recognized in the literature. Those are *coupled* and *uncoupled* shared control [2, 3]. In the first, driver and vehicle interact directly through the torque at the steering wheel; the automation acts over the vehicle through an electric motor, while the driver applies the force using the hands and arms. This mechanism allows the driver to own the final authority over the vehicle, provided that it exerts the required torque. In the second case, the driver controls the vehicle indirectly through the automation controller, which acts as a bypass in normal circumstances, and adds an extra command if it is necessary for ensuring performance and safety. Therefore, the automation evaluates the input of the driver and possesses the authority over a control conflict between them.

The algorithms used for this technique vary in a wide range. Classical haptic feedback controllers were the first to be tested using PIDs [4] and artificial potential field [5]. However, optimal control techniques such as MPC [6, 7], LQR [8] and Lyapunov stability design [9] have shown relevant benefits with the inclusion of driver models [10, 11] within the problem formulation. This has allowed a bidirectional communication between drivers and steering assistance systems, reducing efforts and improving performance. Also, game theory approaches appear as a novel technique for designing ADAS using a theoretical implementation and avoiding extensive experimental tests [12, 13].

The variables considered for optimizing the driving task are mostly related to tracking performance, e.g., lateral and heading errors [14]. Also, comfort parameters such as lateral acceleration, steering rate [15], and torque conflicts [16] are of interest. Moreover, latest works are suggesting the relevance when considering the driver status [17], including drowsiness and inattention level. The driver intention and behavior characterization seems appropriate to consider in the driver-automation interaction as well [18].

The most common application for shared control is the lane keeping task [19], where the system corrects the driver's steer command if it is getting out of the lane. But there are further interesting use cases, such as lane change assistance [20], obstacle avoidance [21] and take-over maneuver [22]. Additionally, a recent work on shared control for enhancing roll stability in path following has been presented [23].

The evaluation of these systems has been mainly performed in simulators, with the driver in the loop. However, very few algorithms have been tested in real vehicles. This suggests that future works on this field will include the validation of shared control algorithm in experimental platforms with real drivers and different scenarios, which would be the goal of the HADRIAN project.

This topic is being studied worldwide by different institutions. One of the most relevant groups of investigation is TU Delft, from the Netherlands [24], focused on classical coupled shared control techniques. On the other hand the IRCCyN located in France [25], specializes on optimal control techniques including the driver model within the shared control framework.

4 General Framework

In contrast with highly automated vehicles, shared control requires additional modules that manage the new driver-vehicle interaction. There have been proposals for different frameworks tackling this issue, which pursue the goal of allowing driver and automation to share the authority over the vehicle not only at the control/operational level but also at the decision/tactical level. However, these works are presented from a theoretical point of view. A more practical approach has been studied by other authors [26], although, the architecture is layered by cognitive levels instead of particular modules.

Full automation architecture is well known to be comprised of six main blocks (Acquisition, Perception, Communication, Decision, Control and Actuation) as presented previously in the literature [27]. However, with the inclusion of the driver, a new framework is needed with additional modules that manages the driver-automation collaboration. A brief explanation is given below for each module in order to present the architecture showed in Figure 3.

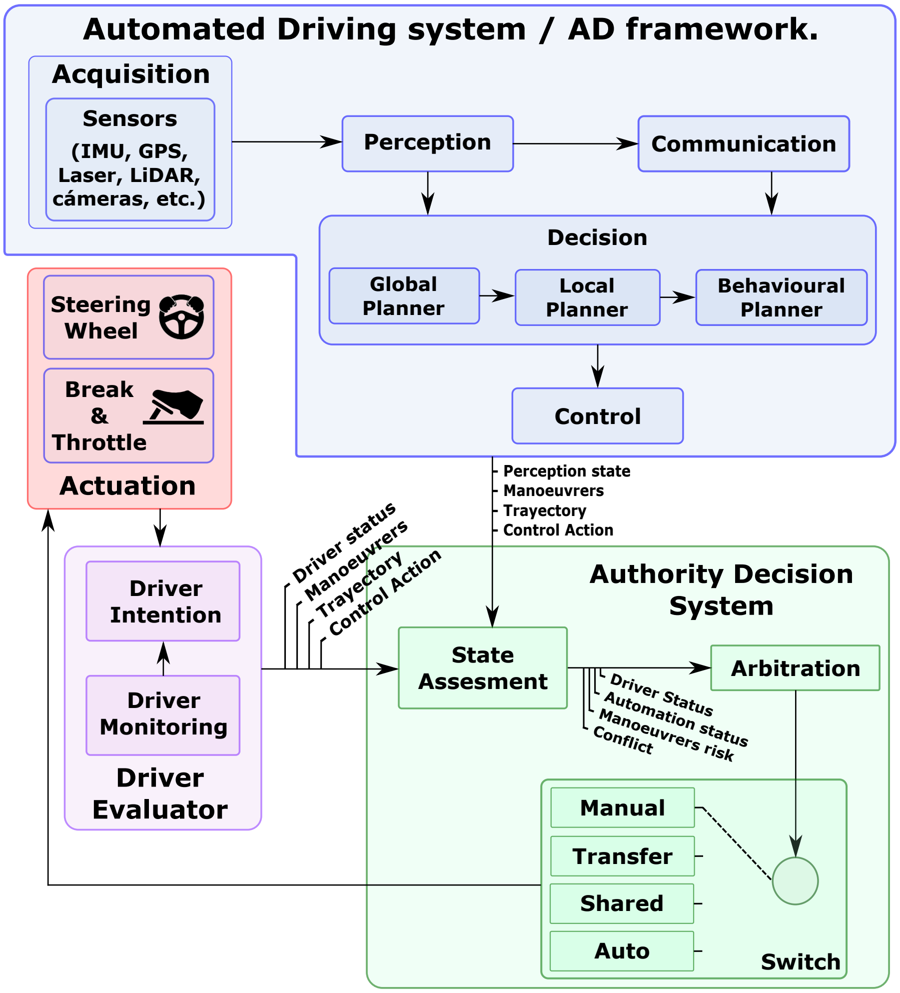

Fig. 3. General Framework for Automated Vehicles with shared control

4.1 Acquisition

Acquisition module collects data from sensors. This data can refer to the environment (Differential GPS (DGPS), Inertial Measurement Unit(IMU), vision sensors, etc.), the vehicle (low level CAN communication, throttle, brake, etc.) and the driver (cameras, Electroencephalograms (EEG), Electrocardiogram (ECG), breath sensors, etc.).

4.2 Perception

This stage uses the data coming from Acquisition module to generate meaningful information about the environment. Moreover, it detects and classifies objects in order to avoid collisions and risky maneuvers. Many techniques within this module have been applied, most of them based machine learning and deep learning algorithms, using sensor fusion, to reduce the uncertainty of the measures.

4.3 Communication

Communication module provides information from other vehicles (Vehicle-to-Vehicle, V2V) or an infrastructure (Vehicle-to-Infrastructure, V2I), to increase the accuracy of environmental description.

4.4 Control

Control stage receives the path to follow and it ensures that the trajectory is executed correctly. However, the Control Sharing is an approach that indicates the authority level that the automatic controller has over the driver. This stage is one of the more complex and studied within automated vehicles. Among the algorithms that have been used for control we can find Model Predictive Control (MPC) [28], PID, Fuzzy Logic and others [29] have been implemented as control techniques.

4.5 Actuation

Actuation module is conformed by the actuators such as throttle, brake and steering wheel. Also, it considers the low level control to the actuators.

4.6 Decision

The core of the control architecture is the decision stage. This process receives information from perception and communication module (and sometimes the input from the world information) and decides the dynamic behaviour of the vehicle. This allows reacting and interacting with unexpected situations that typically affect the predefined driving, such as: obstacles, road works, pedestrians, etc. This stage is formed for three sub-stage: Global Planner, Local Planner and Behavioural Planner. These sub-stage receive the information in order to generate a trajectory that fits to the requirements of the road and also ensures safety driving.

- *Global Planner*: performs the first planning generation process. It is responsible to create an accurate global path by taking into account the information of a map file.
- *Local Planner*: improves the trajectory softness and vehicle comfort using different types of curves, such as Bezier [30] and adding the speed profile.
- *Behavioural Planner*: changes the road conditions taking in account the different dynamics manoeuvres considered, i.e. lane change, obstacle avoidance, overtaking, etc.

4.7 Authority Decision System

The development of algorithms to intelligently share a vehicle authority between the driver and the automatic controller is done in the Authority Decision System module. This stage is composed of following two components.

- *State Assessment*: it is in charge of assessing the agent status regarding its capabilities and risks in a specific scenario. Receives inputs from the driver evaluator and the vehicle. It evaluates the state of each agent involved in the driving task and assess intelligently its risk, taking into account the driver, the vehicle environment, the manoeuvre in execution and the conflict produced by the interaction between driver and automation.
- *Arbitration*: has two specific purposes. First, it decides the driving state of the vehicle: manual (user drives), transfer (the system transfers the control of the vehicle to the driver or vice versa), control shared or auto (the system takes the control of the vehicle). Second, if the control is shared between driver and automation, the arbitration module shall assign the proper authority to each agent.

4.8 Driver Evaluator

The Driver Analysis stage is external to the architecture and it is responsible for analyzing both the state of the driver and its intentions while driving, in order to give sufficient information to the arbitration system. This module can be separated in the following two blocks:

- *Driver Intention*: is in charge of estimating what the driver wants to do in a particular moment of the driving task.
- *Driver Monitoring*: is responsible for detecting the driver state during all the driving task. This block refers to a set of conditions that affect the driver behavior inside the vehicle, such as: distraction, drowsiness(fatigue) and medical conditions. Other factors like surrounding cars and traffic can also affect the driver capabilities.

5 Needs and Challenges of the Implementation

In this section are described some needs and challenges of shared control implementation according to the structure defined in this work.

- *Shared Control*: The main **needs** are the actuators with haptic feedback to ensure a fluid transition between the system and the driver as well as improve the driver trust and acceptance; and the optimal control algorithms designed to complement driver and automation actions. The **challenge** relies on the driver and system interaction because low forces on the actuators can not affect driver understanding and high forces can produce instabilities and discomfort.
- *Driver Monitoring module*: The main **needs** in this module are related to the systems that evaluate the driver state. In the scientific and research field this is a topic of increasing interest and it is not common to find a commercial product that monitors the driver state. However, the **challenge** lies in the sensors for driver monitoring, that is, cameras and lasers are currently the most used devices since it is difficult to obtain the acceptance of drivers to use also intrusive sensors to monitor variables, such as: heart rate, breath, brainwaves, and others.
- *Driver Evaluation module*: The **need** is to detect driver behavior fusing the data of the actuators (encoders and torque sensors) with driver monitoring. The **challenge** focuses on different ways of driving. It is important to adapt the model to a general driver behavior or alternatively, train the model for the current driver preferences.
- *Authority Decision System*: The **challenge** is to develop robust enough decision systems considering all use cases that could occurred in such a complex and dynamic task as driving, specially in urban environments.
- *State Assessment*: The **challenge** is to develop a comprehensive system which can evaluate and aggregate the risks of multiple agents. Another issue, is the scalability and generality of the problem, the assessment performed should be able to translate to different scenarios, where most works focus in very specific use cases.
- *Arbitration module*: The **needs** are related with the state assessment outputs. So, a proper and accurate definition of the state machine is a **challenge** for its design in terms of to conclude who takes the vehicle control based on the risk analysis of both the driver and the environment.
- *External interfaces*: On the other hand, Human-Machine-Interfaces (HMI) are a great **need** to make the driver understand the automation intention, state, and actions. In this sense, the system can communicate information to the driver by 1) a visual screen, through text or images, for example showing the representation of the environment with nearby vehicles, 2) haptic interfaces, using vibration in the pilot seat, at the steering wheel, or any other surface in contact with the driver, and 3) audio warnings, either by sound alerts or tutoring voice. The **challenge** is to design such interfaces in order to increase driver understanding and avoid excessive information that can overwhelm the driver.

6 Conclusions and Future Works

This paper presents a framework for shared control in automated vehicles. More specifically, it describes the necessary modules that need to be included in the general automated driving architecture to manage the complex interaction between drivers and vehicles. The modules: Driver Evaluator and Authority Decision System have been defined.

The main contribution of this work is the definition of the general framework for cooperative control between driver and automation such as shared and traded control, considering different modules, as the driver and risk evaluation of the environment. This contribution represents the basic needs for achieving a safe and effective human-machine interaction in Automated Driving. as future work, the needs and challenges defined, in this work, will be implemented in the framework of the EU-H2020 Hadrian project, using different Use-Cases. Moreover, real vehicle implementation will be considered, based on real-time information.

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