# Fluid interface concept for automated driving

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**Abstract.** The biggest challenge for a human-machine interface in highly automated vehicles is to provide enough information to the potentially unaware human operator to induce an appropriate response avoiding cognitive overload. Current interface design struggles to provide timely and relevant information tailored for future driver's needs. Therefore, a new human-centered approach is required to connect drivers, vehicles and infrastructures and account for non-driving related activities in the forthcoming automated vehicles. A viable solution derives from a holistic approach that merges technological tools with human factors knowledge, to enable the understanding and resolution of potential usability, trust and acceptance issues. In this paper, the human factors challenges introduced by automated driving provide the starting point for the conceptualization of a new Fluid interface. The requirements for the new concept are derived from a systematic analysis of the necessary interactions among driver, vehicle and environment. Therefore, the characteristics, components and functions of the interface are described at a theoretical level and compared to alternative solutions.

**Keywords:** Automated driving, adaptive interface, mobility needs.

## 1 The need for a new concept

In highly automated systems the design of human-machine interfaces is mostly driven by technology development rather than by the characteristics and skills of the humans who should manage them. However, the more automation works independently from human intervention, the more likely it is that humans are not able to intervene if necessary, because of a lack of attention and inadequacy of the interfaces. The challenge is then to design an interface capable of providing enough information to the human operator who may be unaware of what is happening, while at the same time to induce a rapid response without overloading the operator with information. This cannot be achieved without consideration for the human factors from the start of the design process of the system. This is even more true in the context of driving automation which is changing the relationship between drivers, vehicles and environment in a way that is not yet fully understood. Indeed, highly automated vehicles will need to accommodate a variety of functions and will therefore require an unprecedented flexibility of the interface to communicate and switch control to and from humans. Yet, current interface design struggles to provide timely and relevant information tailored for future driver's needs. Therefore, the way (human) drivers and (automated) vehicles interact and communicate with each other needs to be rethought. A new human-centered approach is required to connect drivers, vehicles and infrastructures and account for non-driving related activities in the forthcoming automated vehicles (AV). A viable approach seems to derive from a holistic perspective that puts together technology-based solutions, which are or will become available with the progress of sensor technology and data science, and human-factors knowledge, which helps identifying and resolving potential usability, trust and acceptance issues. In this paper, the human factors issues and mobility needs posed by automated vehicles are first reviewed. Then, the theoretical characteristics and functions of a new HMI approach to overcome the issues are derived and described. Finally, the envisioned interface concept is compared to other solutions. The HMI concept introduced here is being developed within the European project HADRIAN.

### 1.1 From human factors and mobility needs to interface requirements

To understand whether a new interface concept is needed for highly automated vehicles and how that should work, it is necessary to analyze in detail what the needs of their operators will be. The basic assumption is that the complexity of technology has only recently reached a level that enables a real interaction between operator and vehicle. This means that the vehicle has now (partial) access to the operator's psychophysical states and mental models about the vehicle itself, and the operator has access to the vehicle states with context-relevant information. Moreover, for the first time in the automotive history, the vehicle can operate independently and affect the operator's states, while the operator can demand vehicle configurations that are not related to driving activities. The novel issue is therefore the necessity to keep a constant exchange of information between operator and vehicle, considering also the external, environmental conditions. The challenge is even more difficult given the limitations of sensing and communication technologies on one side, and the limited human ability to oversee and select relevant information from multiple, concurrent sources on the other side.

According to [1], an interface for AV should explain the details and technological features of the driving systems; help create realistic mental models of the complex interactions between vehicles, sensors and environment; present the features progressively, so occupants can build this knowledge with time. Moreover, the interface should *"…convey to occupants the sensed hazards and the shared knowledge received from the other vehicles or infrastructure, so users can acknowledge that the system is aware of hazards beyond the field of view."* (cit. [1]).

Other studies [2], [3] provide an interesting overview of the opinions of several human factors experts on what issues need to be addressed by automated vehicle interfaces. The experts indicated that an AV should provide information about its status and limitations and enable a safe transition between automated and manual driving mode. Interestingly, specific trainings are to be envisioned to ensure drivers can efficiently and safely operate automated vehicles [3]. Moreover, a cross-national large study also indicates that the public has a high acceptance of automated vehicles when they can be perceived as useful and easy to use, pleasant and trustful [4].

In addition to the information challenge, Cunningham et al. [5] have identified and reviewed a series of potential human factors issues in highly automated driving. The driver could become less attentive or distracted, loosing situational awareness and the ability to promptly react to a critical situation [6]. This could also induce mode confusion, i.e. the misunderstanding about which functions are under control of the automated system and which are under human responsibility. Another critical issue arises when the operator's trust in an automated system exceeds the actual capabilities of that system, resulting in an insufficient countercheck of the automation status, i.e. reduced monitoring behavior, and an abuse of the system in situations that are not suitable. Conversely under-trust in the automation may result in low acceptance rate of the technology and the waiver of the potential benefits. Long [7] and short-term [8] impairments of driving skills have also been reported after exposure to automated driving sessions, likely due to sensory and cognitive adaptation processes. Finally, the condition of motion sickness, characterized by symptoms of nausea, headache, and general discomfort, is expected to worsen in automated vehicles [9], [10], i.e. when the driver becomes a passenger. This is supposedly a consequence of an increased sensory mismatch between visual and vestibular input [11] and a reduced controllability over the current vehicle motion (see [12] for a review). Moreover, it seems plausible to expect a further increase in motion sickness rate with rearward facing seats arrangement [13], which could possibly be adopted for non-driving activities enabled by the automation.

The solutions to these problems are not so straight forward, and many studies are investigating how information can be efficiently conveyed within an automated vehicle. For example, the results of a preliminary study [14] suggest that the timing in providing explanation of events plays an important role in trust building towards AV. Also, explanations provided before actions seem to promote more trust than explanations provided afterwards. Another recent paper [15] suggests that robotics, machine learning, psychology, economics, and politics are needed to address the challenges of automated driving and proposes a few principles underlying the human-centered autonomous vehicle. Among others, these principles refer to the *shared autonomy* between human driver and automated system to jointly maintain a sufficient situation awareness of the driving activities. For an extensive review and very insightful recommendations of HMI design principles and practice it is useful to refer to [16]–[18].

Overall, there seems to be a general agreement around the new human-factors challenges posed by the introduction of automated driving. Those challenges revolve around the general mobility needs for safety, comfort, acceptance, trust, and connectivity. These general needs do not seem to differ between automated and traditional driving scenarios. However, in the new landscape of mobility the complexity of the interactions among entities like human drivers, vehicles with different levels of automation, and environment with connected infrastructure and vulnerable road users tends to increase significantly. Therefore, it is important to analyze the mobility needs within the perspective of all three components – driver, vehicle and environment, to inform the design of an interface for the upcoming scenarios.

In Table 1 the general needs of driving scenarios (first column) are translated in requirements for each mobility component – driver, vehicle and environment – of complex, automated driving scenarios. In the following paragraphs, a description of the table contents is produced.

**Table 1.** Driver, vehicle and environment needs in automated driving.

| | *Driver* | *Vehicle* | *Environment* |
|---|---|---|---|
| **Safety** | High situational awareness, low cognitive load | Monitoring sensors, state extraction algorithms | Monitoring road, traffic and weather conditions, standardization |
| **Comfort** | Physical (sensory) and cognitive, for driving and non-driving tasks | Holistic models for internal combustion engine/electric vehicles | Providing databases for services |
| **Acceptance** | Foreseeable human-like automated driving behavior | Increased transparency of vehicle behavior in defined situations | Enable information exchange among different road user types |
| **Trust** | Calibrated towards own system and other road users, tutoring system | Feedback interface, adaptive algorithms learning over time | Maintaining up-to-date databases |
| **Connectivity** | Multi-sensory natural interaction via gaze, gesture, speech, touch, audio, visual | Multi-display, ensured connectivity, flexible control strategies | Fast connectivity across platforms, devices, sensors, |

### Driver

The driver needs to receive updated information to keep high **situational awareness**, or to able to regain situational awareness quickly and efficiently. This should occur in a **non-obtrusive** way, i.e., without adding more and more warning signals or increasing the information density on the available displays. Also, AV operators must always be able to attribute the **responsibility** of driving task. Thus, they must know what tasks they are responsible for at any point in time, regardless of their current activities. Conversely, they need to **avoid overload** of information, as they do not need to know the whole time every vehicle-related information that is not immediately relevant. The interface should also enable a high level of **connectivity** for the driver and passengers. This is particularly relevant for safety-oriented applications stemming from vehicle-to-vehicle or vehicle-to-infrastructure communication. Moreover, it is rather evident that any person nowadays must be connected in order to carry out a series of work, leisure and personal activities. So, the need for connectivity does not only reflect safety requirements but is also socially relevant. To guarantee safety, comfort and acceptance, it will be essential for the user to be able to **communicate naturally** with the interface. This could mean to make use of technologies that recognize natural speech, but also intentions from gesture or gaze direction. The driver needs to be supported in the learning of the complex automated driving system, to be able to use it in a way that can eventually relive the driver from the driving tasks and responsibilities. In other words, the driver needs to achieve a proficient use of the new technology and at the same time maintain an assuring feeling of ‘familiarity’. Trust towards the vehicle and its systems must therefore also be calibrated with step-by-step approaches, that bring the understanding of the user to the appropriate level. **Calibrated trust** is also necessary among different road users, as, e.g., pedestrian must be able to recognize and understand vehicles' intentions, and vice versa.

**Vehicle**

From the vehicle side, the main need is to keep an updated status of occupants and environment conditions to ensure safety and comfort. This means **monitoring** driver and environmental states, in order to plan the travel conditions and the switching of control between system and driver across different automation levels and road conditions. On one side, this requires active and constant communication between infrastructure and on-board sensors, to keep track of environmental conditions both in proximity of the vehicle or remotely. On the other side, monitoring of the driver and passengers' conditions is essential to guarantee prompt reactions or even anticipatory behavior. Also, vehicles must be equipped with **holistic comfort models**, that can take into account how the conditions for optimal comfort change across automation levels, and depending on the activities of the occupants, or even the powertrain of the vehicle. It becomes more and more evident that traditional vehicle interfaces are not capable of handling such an amount of information and, even more importantly, the interaction with driver and passengers towards the interior, and the other road users and infrastructure towards the exterior of the vehicle. Therefore, it is required to develop **multi-display** and **multi-sensory** interfaces, that can reproduce redundant and complementary signals using a broader bandwidth. Finally, a timely and efficient communication and interaction with the occupants require a **fast processing** of data collected by the onboard sensors or retrieved by connected devices or infrastructure. This can be achieved only by a combination of **artificial intelligence** algorithms and **model-based** engineering.

**Environment**

The other components of road traffic, which act outside the vehicle and form together what is referred here as the 'environment', include other vehicles, vulnerable road users, infrastructure, geographical and weather information. This environment needs to be able to **receive and distribute information** from and to the vehicles and any other connected entity. Indeed, the presence of a powerful **connectivity** infrastructure seems to be the essential requirement for enabling most of the functions that will be deployed with automated driving.

## 1.2 Current concepts, prototypes and visions

In the last few years, several concepts have been proposed to create a user interface for automated vehicles that enables non-driving activities and supports transition of control. Here is a short overview of some of the most impactful concepts. It is important to notice that the concepts show similarities with each other and with Fluid, but also remarkable differences stemming from the different goals of the interface. The purpose of this section is therefore to illustrate how different players intend to address the needs and requirements described in the previous section. In the section 3, a comparison between Fluid and these concepts is proposed.

**Fig. 1.** Representation of the HMI concepts for AV described in the main text. From top right, clockwise: BMW ZeroG Lounger, Renault Symbioz, Toyota Concept-I, Daimler Vision AVTR, BMW i Interaction EASE, Nissan Invisible-to-Visible, Audi Experience Ride, Mercedes-Benz F015 Luxury in Motion.

**Audi.** has proposed the Audi Experience Ride, a virtual reality headset-based entertainment system providing passengers with interactive contents that move consistently with the movement of the vehicle to increase comfort and the "connection with the road" [19]. This technology fuses vehicle data, geodata and content data. The complementary system Audi Immersive In-Car Entertainment implements car body movements to match the motion of the contents the passengers are seeing on an otherwise stationary vehicle [20]. The immersion is enhanced by adding multisensory information including, e.g. seat vibrations, sound, heating and interior light animations.

**Toyota.** has introduced Concept-I and a humanized interface acting as a friendly “liaison between passengers and the car” to create a “special bond between the driver, the car and the world around the driver” [21]. The system is designed to detect what the driver is “thinking, feeling and needing” to ensure the driver is “always happy”, with the ability of learning over time using artificial intelligence. Ultimately such a system should also be capable of detecting driver’s fatigue and take over driving control.

**Nissan.** has recently presented the Invisible-to-Visible technology [22]. Such a system should merge sensors information from inside and outside the vehicle with infrastructure data and visualize it through human-like avatars inside the car (covering the driver’s full visual field) to inform the passengers about any current or upcoming conditions on the road ahead, including visibility, pedestrians and guidance. In addition, it can also monitor occupants’ state and suggest assistance if the situation requires.

**MIT.** highlights the need for sensing human cognitive load, activities, hand and body position and glance region, together with the desired deep personalization of vehicle operational aspects, to reflect the specific experiences of the vehicle and an individual driver that cumulate over time [15]. The authors propose a solution with a large central display on the dashboard to indicate with the use of stylized icons who is currently in charge of the driving task.

**Daimler.** Vision AVTR is described as a concept vehicle in which interior and exterior merge in an holistic view [23]. The design process focuses on the perception and needs of the passengers with the goal of extending their perception from inside out, creating an immersive space in which passengers are connect with each other, with the vehicle and the surroundings. In the 2015 prototype F015 Luxury in Motion Mercedes-Benz showed also the use of large displays on the door panels, which could show animated particles with the purpose of reducing the visual mismatch between vehicle interior and actual vehicle body motion with respect to the environment [24]. This solution is expected to mitigate motion sickness symptoms.

**BMW.** i Interaction EASE, and ZeroG Lounger [25]. The first concept focuses on a natural interaction between human and automated systems and enables three operating modes: “Explore, Entertain, Ease”. In “Explore” users’ gaze and pointing are sensed for respectively browsing and selecting the space around the occupants and the vehicle. A full-windscreen sized Head-Up display works as augmented-reality display on which additional information are over-imposed to the real-world view. In “Entertain” the side windows are darkened to isolate from the outside, while on the interior theatre-like ambient lights adapt to the contents displayed on the windscreen, which is used to stream media. In the “Ease” mode the seat assumes a “zero-gravity” position and all the screens and windows are darkened to allow a more relaxing environment.

**Renault.** Symbioz [26]. The cabin layout has been conceived as a connected extension of the house and designed as if driver and passengers were sitting in a living-room. The door panels feature built-in lighting. Head-mounted displays offer an immersive VR experience that incorporates inputs from vehicle dynamics data as well as objects detected by the sensors. During the journey, passengers wearing the VR headset experience a transition from augmented reality to virtual reality, drifting from a realistic visualization to a completely fantastic environment. Floating objects in the virtual world provide visual references about the actual motion of the vehicle, to maintain the coherence between the virtual and physical dimensions, ensuring a comfortable experience.

Overall, all concepts address the needs for safety, comfort, trust, acceptance, and connectivity, as previously described. Commonalities and differences in the described concepts can be appreciated by a visual inspection of Fig. 1. However, it is worth reporting here a few features to summarize what is to be expected from an HMI for automated vehicles, given the current landscape.

- Most of the concepts imply either a full-size windscreen head-up display or the use of a head-mounted display to provide virtual/augmented reality contents. This indicates the trend of OEMs to provide an **immersive visual experience** to the occupants. This seems to be the answer to the need for information, communication and connectivity of AV passengers as described above. It reflects also the new mobility need for connectivity and entertainment, as introduced in section 1.1 and Table 1.
- Another common aspect in the concepts is the **connection between interior and exterior** of the vehicle. This exchange of sensed data and information between the driver and the outside world is conceived to increase the comfort of the occupants and to expand the range of interactivity. The first goal is achieved by connecting what is visually displayed inside the vehicle with what is physically happening in its proximity. The second goal is achieved by connecting the on-board controls with remote sensors in the environment, so that the vehicle can become an extension of the living spaces. Interestingly, the same technology can also be used in the opposite way to improve the entertainment experience and isolate the passengers from the surroundings.
- Another aspect that is worth mentioning is the **humanized interface**. In some concepts this is implemented as a human-like virtual assistant, which transform the vehicle into a human companion; while in others the concept is less extreme, and only specific features like natural language and other forms of interactions are implemented to make the use of the interface more intuitive.

Similarly, Fluid has also been conceived to address the same mobility needs, as described in the next section.

## 2 Fluid concept

Fluid is the expression of a holistic approach that aims at addressing the main human-factors challenges of automated driving in the upcoming mobility scenarios. Like a fluid, an interface based on this approach surrounds the driver and continuously adapts to support any change in his/her psychophysical state. Fluid is meant to increase situational awareness, minimize obtrusiveness of traditional visual and auditory interfaces, and preserve the driver's cognitive spare capacity for a prompt and smooth transition of control, while providing a comfortable and safe experience. Fluid is a concept of holistic interface to mediate the interactions between driver and vehicle or any other connected entity, as well as between vehicle and other agents in the external environment.

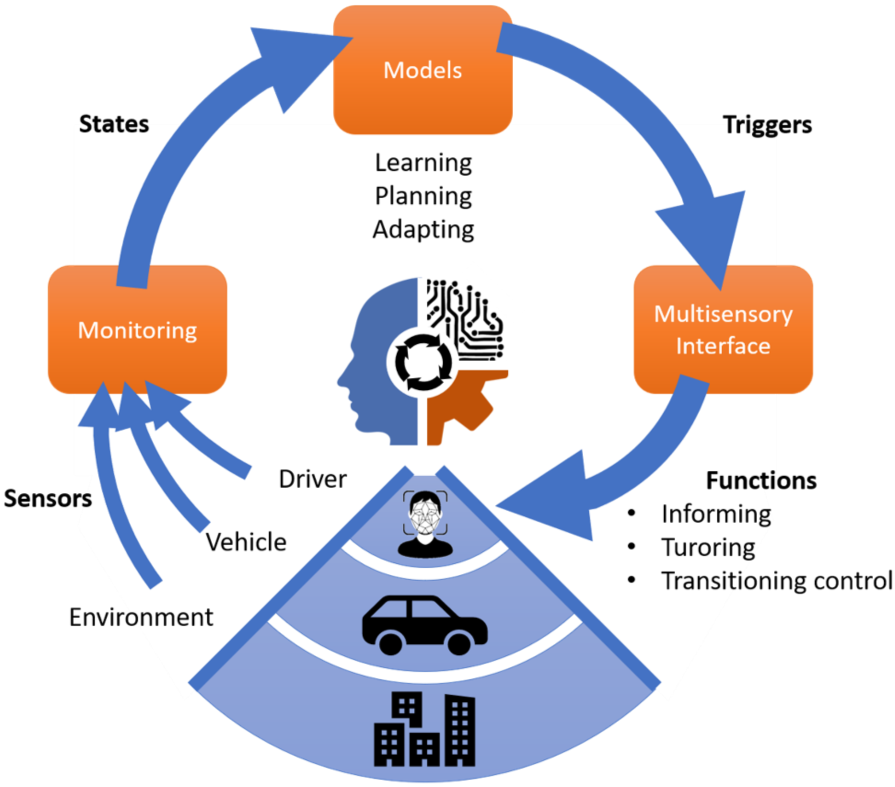


**Fig. 2.** Scheme of the Fluid concept.

### 2.1 Fluid characteristics

Fluid is envisioned as a multisensory, omnipresent and omnidirectional system that constantly monitors the driver's activities and attentional levels, vehicle state and environmental conditions to update a "digital twin" model. Such a model consists of a representation of the driver's state and preferences over time, in relation with the vehicle and environmental conditions. The updates in the model enable context-based interpretations of the sensed information. Then, proper sensory modality, timing and locations are selected to initiate and seamlessly carry on a natural interaction with the driver through a fluid interface (Fig. 2).

**Omnidirectional interface**

The interface consists of visual, auditory and haptic displays, allowing information to "flow" across different sensory modalities and around the driver, adapted to his/her current activity and focus of attention. Fluid interfaces are an extension of adaptive interfaces as they continuously adapt to the human operator depending on the changes in the configuration between driver, vehicle and environment. Moreover, fluid interfaces extend beyond the physical boundaries of a dashboard, as they can include the windshield and seats, as well as door panels and roof/floor. Therefore, fluid interfaces have the potential to revolutionize car interiors and traditional interface design, embracing and surrounding the occupants. In that sense Fluid is an omnidirectional interface, capable of providing information everywhere in the vehicle interiors. Fluid is also an omnipresent system, which is constantly running in the background, collecting data from onboard dedicated sensors, but also from available connected wearables or infrastructure network. The system is seamlessly integrated in all aspects of vehicle functions, but it extends even beyond the vehicle, as it makes use of data collected by smartphones and wearables. This guarantees a constant update to the digital twins that contribute to the decisions of the interface even when the driver is not in the vehicle.

In a fluid interface information flow seamlessly across displays, regardless of whether they are visual, auditory or haptic, to convey the information wherever the driver has allocated attention in that specific moment. The driver may also indicate explicitly to the interface the preferred interaction modality, but it is the interface and its model-based decision logics that decides the priority of the interaction with the driver (e.g. for safety-critical situations) and the consequent appropriate modality to initiate the interaction. The focus of attention and the available sensory modality of the driver, i.e. the most appropriate sensory channel for an efficient interaction, are estimated based on the monitoring activities that are constantly running in the background. For example, if the driver is reading a book, a visual display will not be able to efficiently convey a warning signal. Therefore, the fluid interface will redirect the intended signal towards an auditory display and issue, e.g., a sound.

Within the European project HADRIAN, Fluid interface concept is being embedded in several technological solutions that exploit the 'fluidity' of the system. A haptic steering wheel is used to provide feedback during shared control, i.e. collaborative driving between human and automation, and to support a gradual transition of control from automated to manual driving. Moreover, a full-windscreen Head-Up display is being designed to facilitate human-vehicle interactions. This visual display will fulfill two purposes: first, to highlight critical objects within the visual field in a way that is consistent with the driver point of view; second, to provide visual explanations and feedbacks about specific intervention on the vehicle operations.

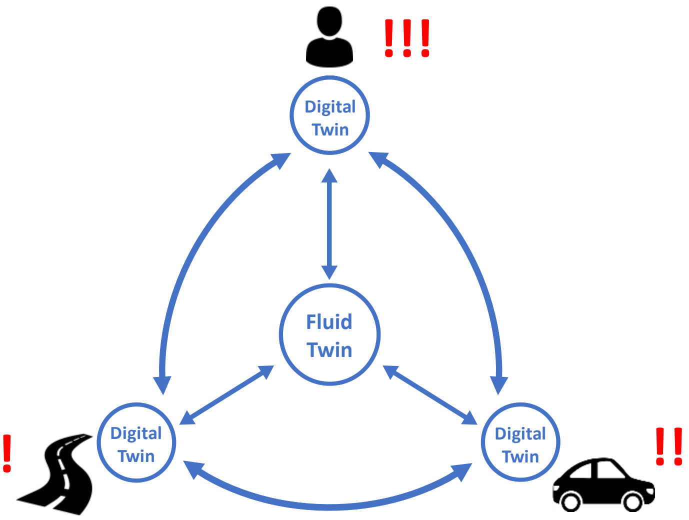


**Fig. 3.** Fluid digital twins. Driver (top), vehicle (right) and environment (left) models, as well as their possible interactions, are represented and updated inside the central fluid digital twin with different priority, as indicated by the number of exclamation marks.

**Digital twin**

Fluid digital twin models offer context-based interpretations of sensed data from driver, vehicle and environment and their interactions (Fig. 3). For each entity the history of the sensed information is stored and updated over time to integrate new learned information. The priority of how data are collected and stored is dictated by the dynamics of the entity. Therefore, the driver history is updated more frequently than the vehicle history, as the driver's status is changing more rapidly and frequently during a single trip, for different times of the day, because of the interactions with the environment and onboard connected devices, etc. For example, heart rate monitoring functions – monitored by on board sensors or wearable devices – can detect a sustained increment while the driver is talking on the phone, and a fluid interface could decide to start a relaxing seat massage program. Interestingly, a similar feature has been recently announced and is expected to enter the market soon [27]. In another example the driver history could show that a certain route through the city at a given time of the day produces an increased heart rate based on the driver history. The interface could then suggest to the driver, conveniently on time, an alternative route for a more comfortable trip. These features are only possible if a history of the interactions between driver and environment is stored and properly included in a digital twin model that compares the reactions of the driver to a previous state and to the environmental conditions.

Each digital twin is composed of three layers: the *basic* layer contains the generic parameters with the default values; the *adaptable* layer learns over time and adapts to the entity (driver, vehicle or environment) category, group, typical condition, etc.; the *specific* layer adapts to the individual contingencies of the entity. For example, the driver digital twin adapts to individual characteristics that are constant over time (e.g. height, sex, etc.) and to psychophysical states and conditions of the moment (e.g. emotional response, fatigue). The central Fluid Digital Twin is responsible for importing data from the digital twins of driver, vehicle and environment, and for moderating the mutual influences of those models (Fig. 3). Also, it operates the necessary transformations of the acquired data into a meaningful *percept* of the overall state, which can then be shared with other road users.

### *2.2* Fluid functions

The characteristics of Fluid enable the implementation of several functions:

1. **Monitoring** of drivers' states, activities and tasks, as well as of passengers, vehicles and environments.
2. **Transitioning** control, including hand-over/take-over requests and transitions across different levels of automation.
3. **Informing** the driver about vehicle and environment state, as well as incoming situations, in a way that is compatible with current (non-driving) activities.
4. **Learning** of the driver preferences and needs, ranging from interior setup to driving style, going from general to individual settings.
5. **Communicating** outside of the vehicle, with other vehicles (V2V) and infrastructure (V2I, V2X). A newly available type of information that can be shared across vehicles consists, for example, of the driver state. Sharing driver state (e.g. 'distracted') in a connected infrastructure to enable the prediction of driver-induced dangers in mixed-automation traffic will have a relevant impact on safety.
6. **Tutoring** of drivers towards increasing automation levels. This function is particularly relevant in the context of automated driving and is not part of a traditional interfaces. Indeed, it covers the current gap in training procedures, where the driver is often learning by trial-and-error. The tutoring function is context-sensitive and provides a step-by-step training of the driver to develop a complete mental model of the automated system. The tutoring system learns from the driver, from the vehicle and from context data and customizes tutoring sessions accordingly, presenting 'lessons' that are suitable for the current context. The tutoring approach is based on a mapping of the knowledge that is needed to operate higher levels of automation. This includes the understanding of the system functionalities and limitations, obtained through a cognitive task analysis [28] and the construction of knowledge spaces [29] related to driver, vehicle and environment data. This is expected to facilitate the understanding and handling of increasing levels of complexity in automated systems.
7. **Driving style.** A fluid system also aims at increasing driving comfort, i.e. provide the occupant of an automated vehicle with a driving style that closely resembles the driving style of a human driver. This does not only apply to how an automated system moves, but also to how it acquires data and extracts, uses and shares information about the surrounding conditions. Specifically, a fluid driving style scoring system was created that automatically recognizes the driving style providing a continuous indication of how a vehicle behaves with respect to the surrounding vehicles and road conditions, like a driving instructor [30]. An automatic controller can then use

the driving score to shape the behavior of automated vehicles, depending on the traffic conditions, location, local culture and traffic rules.

# 3 Impact, benefits and limitations

The massive introduction of driving automation is expected to decrease the number of accidents, increasing overall traffic safety and efficiency, reducing consumption, reducing travel time and traffic congestions [31]. However, at an individual level, from the perspective of drivers and passengers, the societal benefits may not be directly perceived, and even less accepted. What should then be expected in terms of immediate, perceivable benefits from car occupant? What impact is to be expected from the adoption of automated driving technology, together with Fluid? Fluid is one of the many concepts that are being developed to cope with the open questions and challenges of automated driving, A series of alternative approaches and prototypes have been previously introduced (see 1.2), but there are also other concepts, like adaptive, context-based interfaces, which are widely adopted in information technology. In this section it is described how Fluid relates to the mobility needs and differentiates from the other approaches.

## 3.1 Relationship with mobility needs

Fluid interface is conceived to address the needs for safety, comfort, acceptance, trust and connectivity as described above, adapting to individual preferences of the driver, the specificity of the vehicle and the environment.

Fluid can improve **safety** when using automated vehicles by reducing distraction and cognitive load. Indeed, it creates the conditions for the driver to behave and respond in a safer way and reduces the risk of potentially critical situations. Moreover, the possibility of sharing the state of drivers among neighboring vehicles is also expected to increase safety, as well as acceptance of vehicle behavior.

Fluid can also improve **comfort** as it offers personalized support, information and services when and where needed. This type of interface never intervenes abruptly or unexpectedly, as it considers the characteristics of the driver, the vehicle and the surrounding environment at all times, thanks to the preferences explicitly indicated by the user or his/her responses recorded during previous interactions.

**Acceptance** of automated driving systems is expected to increase as a gradual learning process is establish by the interface to bring the driver up to the necessary knowledge and familiarity with the system and all its functions. Also, functions like the driving style scoring (see 2.2.7) are expected to facilitate an intuitive understanding and acceptance of automated systems, which are then able to react to standard and even critical situations like humans would do.

The development of a fluid tutoring function increases the transparency of the automated system and enables the calibration of driver's **trust**, avoiding over- or under-trust (see 2.2.6 for more details).

Finally, Fluid optimizes the interaction between driver and vehicle. So, on one side, more resources could be spared for entertainment purposes, for which **connectivity** between interior and exterior of the vehicle is required. On the other side, an enhanced connectivity with wearables and surrounding vehicles can increase the overall safety by bringing relevant information to the attention of the driver when and where needed.

### 3.2 Comparison with other concepts

Like other concepts, Fluid is meant to increase the connection with the road and the surrounding environment. It achieves that with sensory augmentation and sensory substitution, i.e. transforming inertial data sensed from the motion of the vehicle into visual cues floating around the occupants' space [32]. This enhances the feeling of motion and contact with the road, reducing symptoms of motion sickness, while at the same time reduces obtrusiveness within the visual field. Moreover, the Fluid visual feedback to driver and passengers uses all available surfaces inside the vehicle but does not require to wear head-mounted display, which can result in discomfort over time.

Fluid concept enables an unprecedented freedom in interface design. The way information is displayed (where, how, how often, in which sensory modality) is no longer predetermined for each scenario, but it is decided from time to time, according to the states of the driver, vehicle and environment. In fact, the interaction with the driver becomes polymorphic, i.e. capable of assuming different forms and layouts based on the context.

With a fluid approach, mobility needs can be addressed from a holistic, human-centered perspective, avoiding the situation in which a technological device shapes the interaction with the user. Within the HADRIAN European project, the user needs are the starting point, and so is the Fluid approach. Therefore, it is expected that acceptance for a Fluid-based solution will be higher, and its adoption faster, than for competing concepts.

A specific advantage of a fluid system is that it can be transferred across different vehicles. When a fluid interface has learned the preferences of a specific user, it can enable similar functions in different vehicles. When the user changes vehicle, the system can update the vehicle accordingly to the personalized and most up-to-date settings, regardless of the different interiors layout. What will be transferred is not necessarily the layout of an icon, but the logics of how information should flow across the different sensory channels and displays. This clearly would provide beneficial effects also in terms of standardization and adoption of safety criteria for automated vehicle interfaces.

A difference between Fluid and some of the concepts [22] consists in the level of "humanization" of the interface. Indeed, Fluid does not require a humanized assistant to work, as it does not pretend that the vehicle control system is represented with human appearance. However, the way occupants can interact with the system takes advantage of natural human interactions, like e.g. gesture and body motion, as well as gaze and pointing. This is also in line with what [15] has proposed.

One might consider Fluid to be an adaptive, context-sensitive user interface, assuming that those interfaces can cope with the complexity of automated driving. Indeed, an adaptive/adaptable user interface [33] can change its layout according to the user's needs and expertise, while the context-sensitive feature increases its efficiency similarly to what graphical user interfaces for desktop applications do [34]. However, even though a fluid interface has undoubtedly aspects that are adaptive and adaptable based on contextual information, it also implies the definition of a ‘context’ that goes well beyond the traditional meaning. Instead of the interactions between driver and vehicle functions, similarly to what happens in a desktop environment, here the context refers to the possible interactions between driver, vehicle and environment. The three entities are treated as a single system, and therefore a single context to which the interface shall adapt, but the complexity of the interactions is surely larger. Indeed, the update of the respective models (digital twins) requires dynamics that are different for each of them. The adaptive aspects do not refer to the mere layout changes in the graphical layout of the interface, but to the ability of transferring and conveying information across different communication channels, that connect to different senses of the users, like, e.g. adapting a visual feedback into an auditory one. Finally, a fluid interface does not require the specification of a predefined interface layout, as this will emerge over time over the course of multiple interactions with the operator.

The difficulty of such a fluid interface is in the necessary massive use of artificial intelligence algorithms that must learn and adapt over time to the specific situations, while minimizing the risk of misinterpretation and misunderstanding. Also, the decision logics needs to be first implemented in a series of prototypes. Therefore, several studies need to be planned to inform the design of an integrated mobility system that includes driver, vehicle and environment features. Finally, the necessary coordination among different manufacturers, as well as the intensive collaboration required across different disciplines, seem to be a difficult step for the development of the concept.

However, these difficulties seem worth the effort, given the many expected benefits of a fluid system. Overall, Fluid merges the advantages provided by an adaptive, flexible and personalized interface with the need of having an efficient and rapid way of informing the driver about the situation and converging his/her attention towards relevant aspects. It has therefore the potential to enable a wider and faster adoption of automated driving.

## Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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