An exploration UX Automotive in the 5G era: New interaction processes through gesture control and haptic feedback.

Venanzio Arquilla[1], Fausto Brevi[1], Federica Caruso[1],
Flora Gaetani[1], Peng Lu[1]

[1]Department of Design, Politecnico di Milano
venanzio.arquilla@polimi.it
fausto.brevi@polimi.it
federica.caruso@polimi.it
flora.gaetani@polimi.it
peng.lu@polimi.it

Abstract. Cars are becoming smart devices with intelligent interfaces that fit into the smart driving environment, able to connect and coordinate with each other to ensure seamless user adoption. This is the context for the BASE5G project, a multidisciplinary project that aims to harness the potential of 5G connectivity to design adaptive urban environments in which cars are part of complex, infrastructure-integrated systems. The proposed work recounts the experience of designing the interior of a shared self-driving vehicle, with a focus on interface design. The interface design explores a touchless user interaction model involving a gesture-based control system implemented by haptic feedback. The project aims to explore a design scenario for an experiential car interface and interior that considers new visualisation and interaction paradigms in future mobility.

Keywords: User Experience, Sharing Mobility, Autonomous Driving, 5G Connection, User Interface

1 Introduction

The world is witnessing disruptive transitions in the automotive industry. With the rapid development of artificial intelligence and the Internet of Things (IoT) technology, the European Commission has suggested that automated mobility be deployed on a large scale and the full potential of data unleashed by 2030 by [1]. Furthermore, the notion of Mobility-as-a-Service (MaaS), which is often described as a one-stop platform digitally unifying trip creation, purchase and delivery [2] has been raised. MaaS changes the existing concept vehicle ownership and indeed the business model of the mobility industry. In summary, the automobile world is going through four main trends:

1. **Electrification**: reducing the dependence on fossil fuels and switching to battery-based vehicles.
2. **Autonomous Driving**: (semi-)autonomous cars are becoming more available.
3. **Connectivity**: with the increase in car connectivity, a car links not just to other cars but also to the wider online world.
4. **Shared Mobility**: in urban areas, the needs of mobility can be satisfied by shared mobility services.

2 Future of Mobility

According to Coppola and Silvestri, an extensive use of Electric Connected and Autonomous Vehicles (CAVs), i.e., future cars embedded with the latest technologies, along with accommodating infrastructure, characterise the mobility of the future [3]. And it has been suggested that future mobility needs should be considered in both physical and virtual forms [4], wherein the physical mobility represents "*a form of bridging distance to achieve connectivity*" [4], while the virtual form emphasizes the telecommunications aspect. Cars have already become highly complex with interconnected systems [5] consisting of various electronic control units [6]. In the future, this systematic tendency will be apply to all aspects of vehicle usage with the deeper integration of ICT technologies such as ubiquitous computing [7]. The high-level CAV can be recognised as a smart car which is part of the IoT and the Internet of Vehicles thanks to fifth-generation (5G) communication [8].

Cars are becoming smart devices with smart interfaces moving in an intelligent driving environment. Car will be able to connect and coordinate with each other in a decentralized proactive manner to synchronize traffic and driving behaviour [7]. Such a huge increase of automation and connectivity of cars promotes more diverse behaviour and events of users in/with cars. Drivers will have more need for non-driving-related activities with CAVs [11]. As such, the in-vehicle information and infotainment systems and the way people interact with these systems will also see a huge change [12][13], incorporating multi-sensory (including voice, tactile, olfaction, and somato-sensory [14] and multimodal [7] natural interaction for a comprehensive driving experience based on multi-channel user interface (UI). The gradual digitalisation and intelligentisation of cars and the car industry would, in a bigger picture, drive the business model in the automotive industry to shift from a physically-oriented one to a more digitally-oriented one [15]. Automotive companies are recommended to increasingly rely on the integration of attractive value-adding services into value propositions [16], such as offering additional subscription services. For instance, Tesla offers its Advanced Assisted Driving feature as a subscription service to customers who have purchased a specific model [18]. Mercedes-Benz has also recently announced an accelerated subscription service for the *Mercedes-EQ* range of electric vehicles in North America [19].

Moving beyond seeing the car as a digitalized product-service system [20], Mobility as a Service (MaaS) has also been widely discussed as a future context of urban mobility, and is often described as "a one-stop, travel management platform digitally unifying trip creation, purchase and delivery" [2, p. 6]. Shared vehicles in MaaS are recommended to offer a personalized service and a diverse interior layout based on expected UX [21]. Future mobility also plays a critical role in constituting the future smart city. Here, the smart city can be taken as the intelligent driving environment for electric CAVs, and is defined as a city environment where "*investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance*" [22].

Smart mobility is considered to be an important pillar of the smart city concept, which consists of various digital solutions focused on optimizing mobility problems, including traffic congestion, parking, pedestrian safety and urban sprawl [24] [23]. In the future mobility context, the future electric CAV can be taken as a main ICT resource of smart cities [25]. While accessing the vehicular network, cars act as mobile base stations which can be accessed by people inhabiting smart cities via smart devices. In addition, the capabilities of future cars of processing and storing data and information plus their ubiquity in the city can build a network to enable a multitude of services in future cities [25]. Specifically, future cars can outsource part of their computation over neighbourhood resources in cities and this depends on technologies such as the edge computing paradigm, which is supported by 5G mobile networks [26]. As discussed earlier in this paper, we can envision how future mobility boosted by future vehicles would make significant impacts on future living, which can be taken as a sociotechnical system transformation of mobility [27]. There are already several practical commercial projects that explore the implementation of these disruptive technologies. Starting from a self-driving car project in 2009 by Google, *Waymo* has launched the *Waymo One* service in Phoenix, Arizona and San Francisco, California in the USA [29]. Such exciting and anticipated future mobility scenarios cannot be realised without the in-depth integration and use of communication technologies, including 5G [29]. In this paper we explore the innovative design scenarios and challenges that arise from the use of 5G technology in smart vehicles, based on a real-life BASEG project. This name derives from *Broadband interfAces and services for Smart Environments, enabled by 5G technologies*.

3 Project Framing BASE5G

BASE5G was a multidisciplinary research project exploring the different applications of 5G technologies, such as health, didactics, sports, and mobility. *Regione Lombardia* selected this EU-funded project to understand and study the application of 5G technology in the short term. Our research group explores a new hyper-connected urban mobility within this more extensive project. The design team collaborated with the Department of Mechanical Engineering (DMEC) and the Department of Management, Economics, and Industrial Engineering (DIG) of Politecnico di Milano. Company partners are Vodafone, a leading company in communication technologies, and Akkodis, an innovation accelerator company working on automotive design projects. Our research group has identified new urban mobility scenarios and applied some of these to two prototypes (physically and virtually developed). The research presented in this paper focuses on the virtual interactive prototype by redesigning the user experience (UX) in an electric autonomous driving vehicle.

More precisely, the research intends to explore a new interaction process through gesture control and haptic feedback.

3.1 The BASE5G project scenario

The design of the BASE5G car refers to a hyper-connected mobility system that experimentally investigates a new shape and configuration of the car itself. The project framework assumes that the connectivity of 5G and the integration with IoT platforms will transform cars from a means of transport into authentic digital platforms [30]. As noted earlier, products are blurring digital and physical boundaries, and cars are increasingly digitised and connected, which involves a change in product configuration and user interaction. Therefore, the BASE5G car is to be considered part of an integrated communication and data exchange, usually referred to as "*Vehicle-to-Everything*" [8], which involves not only the exchange of data between vehicles but also communication with infrastructure and people's devices [3]. It refers to a seamless experience where multi-device systems dialogue and smart cars become part of the user's device ecosystem [31]. The BASE5G car exchanges dynamic information between people, vehicles and roads and the user's devices are integrated with and connected to cars. The user is at the centre of a mobility ecosystem that can connect to the decentralised and proactive data exchange to personalise the driving experience.

Upon entering the car, users find an environment connected to their digital identity that brings in all their information. The latter may change according to the terms and consents provided by the user on personal data sharing and may include information on likes and dislikes, medical conditions and job positions. With their digital identity, users will bring their data into the vehicle and facilitate integration with personal devices and cloud space, allowing the vehicle's interior to be hyper-personalised (see Fig. 1 below for the aesthetic concept of the BASE5G car).

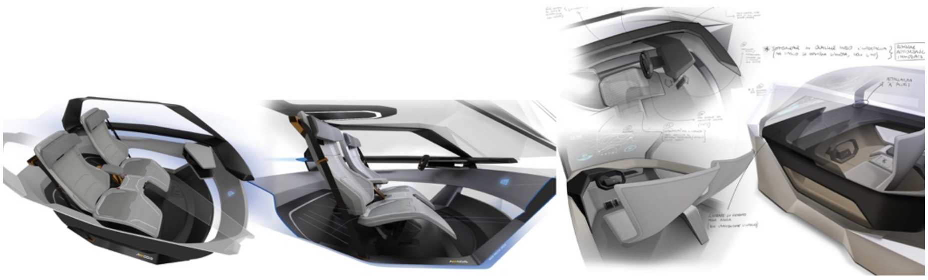

Fig. 1. Aesthetic concept of the BASE5G car with renderings of the car's interior and exterior

The car thus becomes a *Smart Bubble*, a personal and customised space for the user, which communicates with the outside environment to enrich the in-car experience. According to research, future car use will be more than just a means of transport. The vehicle will become an environment in which users can carry out activities, whether work or leisure. The car can become a *Smart Office*, which isolates the user from the outside environment by creating an ideal working environment, or it can become a *Smart Infotainment* space that interacts with the outside world in an integrated and personalised way, providing information from the surrounding environment using augmented reality. These assumptions will inevitably change the car's interior and the cabin's layout. This leads to a new dashboard model in which the steering wheel is hidden, not eliminated, but appears automatically based on the level of autonomy or specific user requests in shared driving control or co-piloting involving the car and the driver. The cockpit will be transformed into a comfortable space and will house the haptic gesture controller. The seats will become cosy armchairs, and the windscreen the communication channel between the car, the user and the city. In the BASE5G car, the interface is projected and visible directly on the windshield using the full-screen Head-Up Display (HUD), which can be interacted with through a gesture-based control system implemented by haptic feedback.

3.2 Driving Simulator Prototype.

The project scenario provides a broad view of the idea. An interactive prototype realised as the project outcome was scaled down to meet time and technological constraints but the result of the research was a driving simulator reproducing the vehicle's interior environment and driving experience.

The interface design explores a touchless user-interaction model involving a gesture-based control system implemented by haptic feedback. The interface incorporates natural multisensory interaction involving voice and touch and is multimodal for a complete driving experience. Since the design process refers to shared mobility designed during a pandemic, it was decided to eliminate all physical control systems and touchscreens in the cockpit.

Moreover, the haptic feedback system aims to improve efficiency and reduce the user's cognitive load during interaction with the interface [31], providing a "*touch*" feeling even without physical elements. The team of engineers was responsible for the technical realisation of the prototype. The prototype was realised in the IDrive Lab of DMEC (Politecnico di Milano), a car simulator that reproduces the windshield using three screens that communicate with a *Stratos Explore from Ultrahaptics* to generate haptic feedback through the controlled emission of ultrasonic waves (see Fig. 2 below).

Fig. 2. IDrive simulator during a demonstration event of the BASE5G project.

In recent years, the automotive industry has started to use the windshield as a media to convey information about the vehicle, giving it an active function [32] Examples of HUDs have recently started to spread in the automotive sector and can be found in several types of vehicles, such as the Mercedes S-Class.

There are conflicting studies on the subject; according to some, the application of the HUD system can reduce the driver's response time to emergencies and make speed control more consistent, while according to other research, the HUD is an obstacle to driving [33] because it is located right in front of the driver's point of view, interfering with the road view. The centrality of the viewpoint, however, is also an opportunity when exploited to display valuable and timely information because it reduces the distance the driver's eyes have to travel to see essential information.

Aware of the current technological limitations, the design choice was to reduce the complexity of fragmented information on multiple screens in the car [14] by focusing information and user attention on the windshield that communicates with the external environment.

3.3 Gesture Interaction Model

The design and engineering teams developed three different haptic interactions, using *LeapMotion* and *UltraHaptics* devices, corresponding to different visual feedbacks within the UI. In this way, users interact with the HUD of the driving simulator prototype.

The three types of haptic gesture interaction and the feedback on the UI are:

1. The first "finger interaction" involves using individual finger movements to activate the interface's main menu functions. When the selection is made, a vibration on the fingertip notifies the user of the activation, and the desired menu opens.
2. The second "swipe interaction" allows users to interact using simple aerial swipe gestures. When the user's hand “touches” two vertical virtual walls, one on the right and one on the left, the user perceives haptic feedback. The interface comes alive by scrolling the menu to the right or left depending on the surface touched; once the desired menu item is reached, it can be selected by simulating a “grab” (closing the hand into a fist), and the interface reacts by opening the chosen section. *UltraHaptics* and UI give feedback each time the gesture is executed correctly.
3. The third "grid interaction" allows users to select information on the windscreen by moving their hand over a virtual grid. Some sub-menus on the interface are designed to maintain a correspondence between haptic feedback and the position of elements on the UI. Users will feel the feedback in their palms and feel that they are touching the various menu icons in grid mode.

3.4 User Interface

The interface was developed considering the three-gesture interaction models the engineering team had implemented. The menu is presented inline and has five items for better finger interaction. Navigation of internal pages is possible thanks to the “swipe interaction” facilitated by the interface UI that suggests the gesture. In more complex cases, such as document selection, document icons are arranged in a grid layout on the screen to match the “grid interaction”.

One of the first design challenges was to organise the information that would usually be spread across several screens in the car on a single screen. Different information architecture and UI hypotheses were tested to define the optimal location and most coherent stylistic layout of the information on the windshield. This phase determined the type and flow of information and denoted the proactivity of the interface. Moreover, the opportunity to iteratively test the interface enabled an accessibility analysis with colour and contrast tests in the virtual environment. The information on the screen was clustered into distinct groups: the ones referring to the *Driving Info*, which include information on speed, driving mode and vehicle status, were designed to be close to the field of view. The *Navigation Info* was placed to reassure the user by showing the route and situation, with an interactive map and traffic information. Finally, there is the *Advanced Control* which, through an exploratory menu, allows navigating all the car's other functions, from HVAC (heating, ventilation, and air conditioning) to the communication system and Infotainment.

Fig. 3. User Interface of driving simulator showing active communication with the city through augmented reality in a partially immersive experience

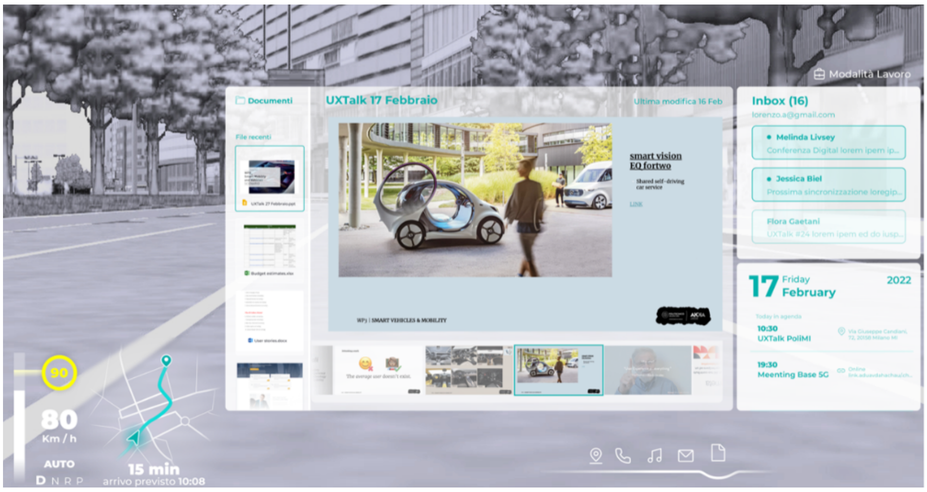

Fig. 3. User Interface of driving simulator showing the immersive experience

A 3D representation of the vehicle is projected onto the interface, allowing the user to proactively control the state of the car relative to the external environment. Augmented reality is also used to increase the immersive dimension with types of experience:

- A partially immersive experience (see Fig. 3 above) in which the interface proactively integrates with the city by giving information about the surrounding buildings (Smart Infotainment).
- A fully immersive experience (see Fig. 4 above) with protection that obscures the external environment and allows complete privacy for or concentration from the user (Smart Office).

In conclusion, the interface is proactive and adapts to different driving situations to reduce the cognitive load on the user and ensure that only the necessary information is displayed on the interface at the appropriate time. The interface design emphasises communication with the external environment and connecting the car with the city.

4 Pilot Test Findings and Conclusions

The research team is working on a series of tests with the virtual prototype to validate the iteration model, better understand the limitations and functionalities, and improve the UX by collecting direct feedback. The test will consist of a simulated walkthrough in which the user can interact with projections on monitors simulating the most realistic scenarios possible. A series of pilot tests were performed, which showed preliminary results that will be validated and further explored during the upcoming user tests.

The results of the pilot tests also showed that gesture control is possible even if a complete de-materialisation of the interface is not feasible. Touchless control needs specific feedback; in this case, haptic feedback improves usability, and the UI can help guide user interaction. In general, the pilot tests showed that touchless interaction requires a preliminary learning moment for the user; during the first tests, we realised that it is necessary to provide an onboarding moment to allow the user to become familiar with gestural interaction.

Three main critical issues emerged concerning the relation between gesture interaction and the HUD interface:

1. Need for contextual feedback notifying the position and presence of the hand: the interface must vary its state by showing clear feedback, e.g., by increasing the brightness of the menu to help the user understand the correct hand position.
2. The most difficult interactions are those that do not map natural user behaviours: "*grid interaction*" is the least natural gesture and, therefore, the most complex to learn and apply correctly, unlike "*swipe interaction*", which is the most intuitive, also because of its obvious parallelism with the interactions we are used to with digital devices.
3. The UI is most helpful in understanding the interaction model: "*finger interaction*" has led to the need for the menu to have an icon layout directly associated with the five fingers of the hand that act as selectors during the gesture.

This research has made it possible to work experimentally by focusing on the interior of the vehicle instead of concentrating on the exterior and power to create an environment that makes driving more productive and enjoyable. The automotive field allows for the practice of a strategic methodological approach, capable of predicting and describing future scenarios, supporting radical innovation processes while at the same time working and stressing design limits, and experimenting and testing design dynamics that lead to radical innovations. Multidisciplinary collaboration in such complex contexts as automotive UX redraws disciplinary boundaries and highlights how specific professional profiles can mutually benefit from cooperation.

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