A Systematic Analysis for Multisensory Virtual Artifacts Design in Immersive E-Sport Applications and Sim-Racing

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Abstract. The mechanics of human-machine interaction have been subjected to numerous influences from the video game industry. With respect to the relationship between transportation and vehicle design and game tech, the area of e-sports and, in particular, that of sim-racing appears to be of particular interest. The perceptual dimension, in its potential as a vehicle for distributed multilevel feedback, becomes a tool that blurs the boundaries of the real-virtual experience due to the potential for spatial and emotional connection that have already been verified in the mixed reality context. The contribution aims to establish and develop a systemic analysis of technologies and approaches used to recreate multimodal perceptual-sensory mechanisms in the context of virtual simulations and in particular in sim-racing devices and e-sports. The analysis and classification of the state of the art is meant to represent a design map to support the designer of digital interfaces in the simulation domain. For the designer of human-computer interaction interfaces, the opportunity emerges to develop innovative interaction patterns and dynamics that exploit multimodality as an input and feedback channel. In this scenario, the role of the interaction designer emerges as a mediator between technological development and the design of the user experience of human-machine interfaces.

Keywords: E-Sport, Simulation, HCI, Sense, Human Body Interaction

1 Introduction

The use of tools and practices derived from the videogame industry in productive sectors different from that of digital entertainment is a topic of growing interest in both academia and industrial research, development and production. Whether we are talking about gamification, applied games, or simulations, the mechanics of human-machine interaction have been subjected to numerous influences from the video game industry. Indeed, it is possible to observe a growing integration between specialized technologies developed and used specifically for different production areas the technologies used in video game production (game-tech). An illustrative case is the use of real-time rendering engines for the construction of digital twins for applications ranging from architectural planning to logistics management of production plants. Such development platforms enable the construction of visualization environments in which topographical and architectural surveys, instrumental data of various types collected through sensors, and processing performed by specialized software converge.

Digital technologies related to Industry 4.0 are bringing a wide variety of innovations in the automotive industries pushing companies to develop new strategies of innovation and fostering the transformation of the relationships between the industry players [1]. With respect to the relationship between transportation and vehicle design and game tech, the area of e-sports and, in particular, that of sim-racing appears to be of particular interest. Competitive driving simulators that take advantage of high-fidelity driving simulation software and real-world driving control hardware replicas, around which there is growing commercial and research interest. During the pandemic crisis, for example, both Formula 1 and NASCAR used virtual sim-racing to continue their activities on live streaming platforms helping to increase interest in this form of entertainment [2]. The transposition of car racing into virtual competitions raises interesting considerations with respect to new dynamics of interaction between athletes' bodies and simulation interfaces. The athlete's body in eMotorSport is "in negotiation with algorithms and processes to quantify its movement. An assemblage that links human and nonhuman, matter and information" [3].

Growing in parallel is the interest in the videogame as a domain for the development of virtual economies in which new modes of consumption and value creation of the commodity form are redefined. This represents a dimension of design and speculation that evolves from the established habit of car companies to design concept cars. In the videogame dimension, players have the opportunity to experience the driving of a concept car whose performances are simulated by the game engine with high level of accuracy. One example is the Ferrari Vision GT, a concept car developed by Ferrari and unveiled in November 2022 and designed specifically for the video game Gran Turismo 7[1].

Within the redefinition of the human-machine interaction paradigm, research poses as an additional element of debate in this problematic field: the assemblage [3], the cyborg [4] and prosthetic [5, 6] connection between human and multisensory interfaces.

The interpretation of perceptual stimuli coming from multiple sources and experienced through different interfaces is a field of the broad project in which multidisciplinary expertise converges. From a design perspective, it is of particular interest to understand the potential of particular sensory feedbacks in relation to human behavior.

Academic research shows that scientific investigation on the relationship between digital technologies and human senses is exponentially increasing with a clear predominance over the sense of sight and proprioception. Less significantly, research is moving on hearing, touch, and forms of multisensory perception [7]. The sense of sight and proprioception appear to be central to the market for immersive digital experiences. Hence, the opportunity for multimodal integration on the other senses within simulation, e-sports and even mixed reality experiences to control real-world parameters is highlighted [8]. With respect to this integration, literature research highlights the potential related to the implementation of feedback through haptic channels. This sensory channel is characterized by multiple properties that can be related to digital applications that exploit the possibilities of transferring sensations of temperature [9], pressure [10], vibration[11], proprioceptive stimuli [12, 13].

The haptic channel turns out to be a guide for the qualitative interpretation of information gathered through the other sensory channels [14], this means that its conscious use can direct the perception of the other senses as well. Through the haptic channel also information can be sent silently and personally, capable in each case of capturing the user's attention [15] with different levels of urgency. It is also evident how in human-machine interfaces the haptic channel is underutilized with respect to the potential related to the widely analyzed body application surface with respect to individual implementable functionalities [16].

Touch turns out to be a suitable channel for delivering information and establishing communication languages for stimulating and interacting with user's peripheral attention [17, 18]. Finally, the tactile channel turns out, as confirmed by experimental validations, to be effective from the point of view of emotional communication [19]. In this direction, haptic sensations are used both parallel to text messages

[1] https://www.ferrari.com/it-IT/corporate/articles/ferrari-vision-gran-turismo

[20] and in synchrony with visual information experienced from the surrounding space [21]. In the former case, haptic cues support the meaning of textual language by increasing its communicative effectiveness; in the latter, they increase engagement with respect to the situation observed by sight.

In describing the driving experience, the vehicle is often described by drivers as an extension of their own body. This description can be ascribed to the debated concept of homuncular flexibility (HF), or the ability of a part of the cerebral cortex to map the body's movements and perceived sensibility onto extraneous physical appendages. The phenomenon of HF has been shown to extend also to virtual appendices [22] opening to a wide range of opportunities and challenges within the human-machine interface research field.

As frequently happens in technological innovation processes, in the area of driving simulators (sim-racing) there is an increasing consumer-level diffusion of instrumentation and technologies that were previously only used in research and industrial development settings. Indeed, it is possible to identify a growing number of commercial applications available on the market that integrate software and hardware to enrich the immersive component of virtual experiences. Through physical interfaces and haptic feedback, it is possible to increase the level of embodiment within the virtual simulation by making it verisimilar to the physical experience [23]. Moreover, professional racing suits and boots, helmets, and gloves are often used in combination with the simulator to further increase the immersion level acting both as diegetic components and physical body constrain/support systems. The perceptual dimension, in its potential as a vehicle for distributed multilevel feedback, becomes a tool that blurs the boundaries of the real-virtual experience due to the potential for spatial and emotional connection that have already been verified in the mixed reality context.

In this contribution we aim to conduct an analysis of the technologies and ways in which the body is related to virtual simulation by providing a useful design map in the development of immersive interaction mechanics.

2 Methodology

The combined use of instrumentation that merges different perceptual stimuli to recreate the illusion of presence and verisimilitude of experience represents a broad project space that crosscuts different disciplines ranging from neuroscience, computer science, game studies, mechanical engineering, and design. The contribution aims to establish and develop a systemic analysis of technologies and approaches used to recreate multimodal perceptual-sensory mechanisms in the context of virtual simulations and in particular in sim-racing devices and e-sports.
Classification criteria were adopted in the collection of case studies in order to better describe the design approaches and the ways in which different technologies were employed. The study compared across multiple aspects forty case studies expressing interfaces and experiences dedicated to simulation and e-sports. The number of cases has been defined in order to develop a flexible, yet detailed classification that will be used to map new case studies during the research activity.

An initial classification of the interface systems between the body and the simulation that is proposed is between diegetic interfaces and mimetic interfaces:

- Diegetic interfaces: the input interface reproduces the morphological, material, and usage characteristics of the virtual counterpart. It is a homologous interface.

- Mimetic interfaces: the input interface has no direct correspondence with the motion or action reproduced in the simulation.

This classification allows interfaces to be categorized on the basis of different modes of interaction. Diegetic interfaces place themselves in a relationship of continuity with the simulated environment by articulating the dialogue between physical space, perception, real environment and simulated environment. An example of this is the steering wheels used in sim-racing whose finishes, geometric and functional characteristics reproduce, in the most advanced and professional models, the features and details of their real-life counterparts. Mimetic interfaces do not preserve a homology relationship between the body movement exerted on the input interface and the action reproduced in the simulation and, therefore, the morphological and material characteristics are also independent of the simulated medium. One example is game controllers, which, through different forms of input (button presses, trigger presses, lever rotations) allow the control of different avatars (whether these are anthropomorphic or vehicles).

The availability of different technologies to return interaction and feedback mechanisms articulates the possibility of combining different technical solutions to be implemented in the design. In defining the combination of components, the designer has the opportunity to develop customized solutions on multiple parameters: cost, complexity of deployment, sensory multichanneling, special needs. In addition, prototyping systems structured according to different combinations of components to return a particular interaction or feedback allows for evaluation of perceptual differences and spillovers in terms of affordance, embodiment, and immersiveness. Technological components can be used to give control inputs or to return response feedback. In the analysis performed on the case studies, information was collected about the presence of visual, auditory and tactile feedback. For completeness, tactile feedbacks were divided into proprioceptive, vibratory, pressure, temperature and electromuscular.

A further criterion for cataloging the case studies emerged with respect to the role that the interfaces play in relation to the human body. To this end, four categories were chosen: prostheses, braces, protectors, and substitutes:

- Prosthetics are understood to be those design elements that intervene in the relationship with the human body in augmenting human motor, perceptual and intellectual capabilities [5] using both passive and interactive approaches [6]. This category has very broad disciplinary boundaries that link the e-sports and simulation industry to artistic experiments related to cyborg culture represented by the works of Sterlac, Harbisson, and Ribas[2], among others;
- Braces are understood to be the category of objects that, through an action of resistance to bodily dynamics [24], provide the virtual reality experience with proprioceptive sensations that contribute to the perception of the shape and size of the elements;
- Protections are the designs that included in the experiences components that have the task of protecting the body immersed in a simulative dimension estranged from the dangers of the surrounding space;
- Substitutes are understood as those tools that replace a human body within interactions.

Therefore, to describe the different types of motion, a classification is proposed that interprets in spatial terms the action performed by the user in interacting with the interface or the feedback of the system on the user's body. A classification is adopted that distinguishes signals (output feedback or input actions) into:

- Punctual: when the signal can be described by locating it at a point (e.g., pulling a trigger);

[2] https://www.cyborgarts.com/

- Linear: when the signal develops along one direction only or very prevalent over the others (e.g., the sliding of a slider along a rail);
- Planar or superficial: when the signal develops along a plane or surface (e.g., electromuscular stimulation distributed over a supporting surface);
- Volumetric: when the signal is collected or distributed in three-dimensional space (e.g., spatial tracking systems).

The choice of sensing system may depend on reasons related to technical/constructive needs or, in the case of diegetic interfaces, on the ergonomic and morphological characteristics of the interface itself. Analysis of this aspect makes it possible to identify parameters of accessibility of the interface with respect to the variety of possible physical limitations or disabilities.

A systematic analysis of the hardware technologies employed in the field of e-sports and the ways in which these can be integrated with each other and with simulation software aims to return design tools based on the perceptual transfer of virtual experience onto the body.

3 Discussion

The analysis of the case studies revealed some design, methodological and technological trends of interest. Among the interfaces investigated, the category of prosthetics clearly prevails (Fig. 1). Within the design field related to simulative interfaces there appears to be a greater tendency to develop elements that are intended to implement human capabilities within the virtual environment. Cases studies in which the design limit, protect or replace the body have been collected in much smaller numbers. Braces are used in more advanced designs to stimulate proprioceptive sensations within the VR experience. Braces are used to ensure the preservation of the integrity of the physical body when the virtual experience involves fast and large movements in space. Finally, only one case of an object substituting itself for an opponent's body has been detected; this is the case of BotBoxer[3] in which the physical punching bag comes alive and dodges punches by real-time control of the human's movement.

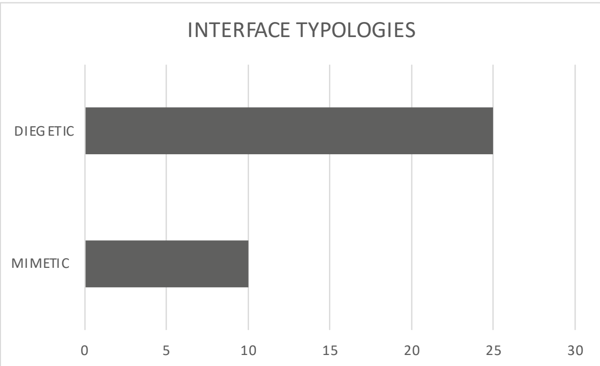

Fig. 1. Interface typologies

Among the collected case studies, the typology of diegetic interfaces prevails (Fig. 2), that is, capable of activating, thanks to symbolic forms, the narrative related to the experience in which users will be immersed. Examples of these interfaces are the multiple immersive experiences related to sports such as

[3] https://www.skytechsport.com/botboxer-home

golf (e.g., Golfzon[4]) or baseball (e.g., Win Reality[5]). Mimetic interfaces are predominantly adopted when attempting to build multi-experience elements or when the interface becomes the movement of the body and thus the devices invade the entire body to track its movement as in the case of climbing of the Red Bull project The Edge[6].

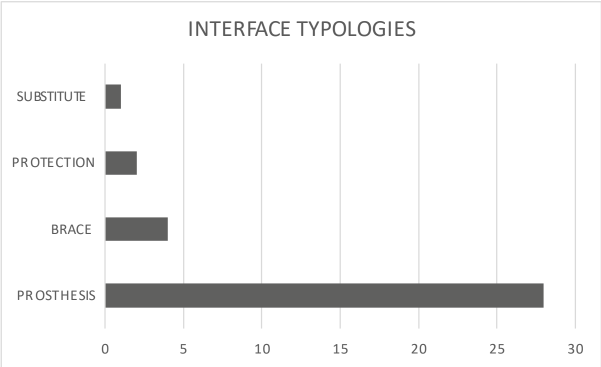

Fig. 2. Diegetic/mimetic interfaces

From the point of view of how interfaces interpret human motion (Fig. 3), the case studies detect two prevailing trends: first, interpreting motion in its maximum volumetric expression, and second, collecting high-quality information about detailed motion, as in the case of Sony's Dual Senses Controller Adaptive Triggers[7]. Linear or planar interpretation of human motion by interfaces is present in case studies that investigate specific motion with high detail quality. Prominent case studies are those of platforms for skiing simulation such as Snowsports Simulators[8] or walking simulators such as Cyberith[9].

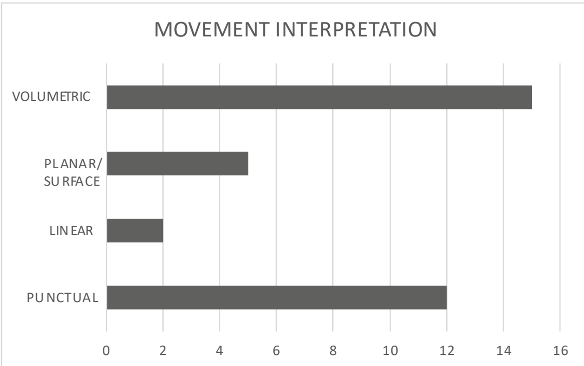

Fig. 3. Movement interpretation

The analysis of the material collected from commercial case studies shows heterogeneous technologies used to stimulate different sensory channels. Detailed data on the technologies used are also often not available. However, the results related to reading the type of sensation sent to users during the

[4] https://golfzongolf.com/
[5] https://winreality.com/
[6] https://www.redbull.com/int-en/projects/the-edge-matterhorn-vr
[7] https://www.theverge.com/21562206/ps5-dualsense-controller-review-games-features-vibrations
[8] https://www.skytechsport.com/ski-simulators-home
[9] https://www.cyberith.com/virtualizer-elite/

experiences appear interesting (Table 4). Since these are mostly immersive experiences, sight and hearing stimuli are always present. In contrast, stimuli related to touch are not yet widespread in market solutions. The observation related to the greater presence of pressure stimuli than vibration is of interest. To a slightly greater extent there are case studies that use systems to give proprioceptive feedback through mechanical actions on the user's body, as in the case of the Blackbox[10]. No designs related to temperature feedback were found in the case studies analyzed, and only Teslasuit[11] uses electromuscular feedback.

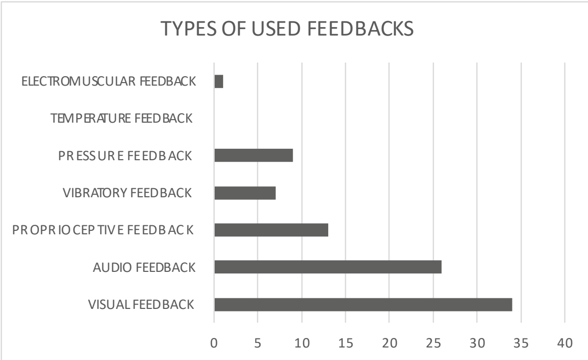

Fig. 4. Types of Feedback

Finally, from the analysis, it is relevant to compare the number of stimuli that are delivered within the individual experiences. In Table 5, the columns represent the number of identified stimuli. Removing the sight and hearing stimuli, the lack of multimodal stimuli is evident for most of the case studies.

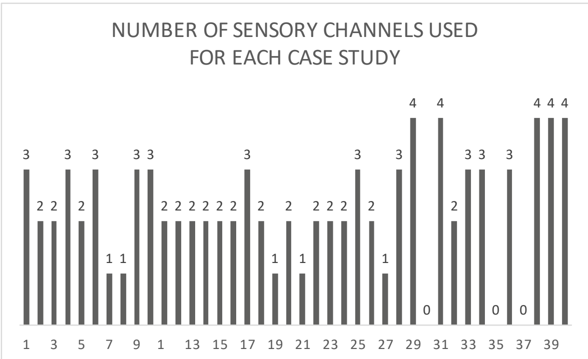

Fig. 5. Number of involved sensory channels

4 Conclusions

The analysis of the case studies confirms the interest in the development of multimodal input/output platforms already investigated in research. For the designer of human-computer interaction interfaces, the possibility of developing innovative interaction models and dynamics that exploit multimodality as an input

10 https://www.blackbox-vr.com/the-hardware/
11 https://teslasuit.io/

and feedback channel emerges. The analysis confirms the growing interest in haptic and auditory feedback interfaces. Further research could be directed at the use of feedback acting through alternative channels such as taste and smell.

In this scenario, the role of the interaction designer emerges as a mediator between technological development and the design of the user experience of human-machine interfaces. The interaction designer's design sensibility in interpreting and mediating the use of interface and simulation technologies turns out to be significant in a phase of strong transformation in the transportation industry. In a industrial sector undergoing a major rethinking with respect to both the types of means of transportation and their use during travel, simulation technologies become a necessary tool for designing and testing new scenarios. Rethinking mobility and transportation using scenarios as a speculative design practice determine the need for tools of analysis and evaluation of the impact of strategic design decisions. In order to bridge the gap with the future, it appears necessary to develop tools to support during the speculative design inquiry. Simulations and interaction interfaces can be an effective control tool, and in particular, it is deemed important to leverage on sensory multichannel interaction whit more accuracy to evaluate choices and directions of innovation in greater detail.

The analysis and classification of the state of the art is meant to represent a design map to support the designer of digital interfaces in the simulation domain. Although the scope of the investigation focuses on human-vehicle interaction, the results may be extended to other areas of human-computer interaction in general to investigate what are possible corridors for future development and innovation on different domains in the context of virtual, augmented and extended reality.

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