Natural and multimodal interfaces for human-machine and human-robot interaction

Main goals of this Ph.D. dissertation are the design, the implementation and the validation of innovative natural interfaces able to efficiently and effectively support the user when interacting with different kind of machines and systems.

The interfaces represent one of the most critical aspect of an interaction system. They act as contact points between the virtual world and the real one. Hence, their development must be carefully planned. In the first part of this thesis, the analysis of several Natural User Interfaces (NUIs) is presented, discussing their underlying mechanisms and highlighting their weaknesses and strengths. Then, among all the possible NUIs, this dissertation will focus on the use of Virtual and Augmented Reality (VR/AR) interfaces to improve the human-machine/human-robot interaction domain with particular interest for the Industry 4.0 context and serious gaming scenario. The VR and AR technologies will be firstly presented by analyzing their functioning and work flow. Afterwards, several original works regarding the use of AR and VR in the Industry 4.0 domain will be presented and detailed. Specifically, by analyzing how AR interfaces are currently employed to improve the efficiency of smart factories, some works related to the use of virtual interfaces to enhance maintenance and training operations will be detailed. Furthermore, virtual robotic teleoperation systems will be also considered, presenting some original works related to the use of RGB-D cameras and immersive VR interfaces to accurately control industrial robot arms. The AR and VR technologies will be also combined in the third chapter, discussing how hybrid virtual environments can be effectively developed, additionally analyzing the impact of the field-of-view (FoV) on the usability of the virtual interfaces in the gaming context.

The thesis concludes discussing its main limitations and some possible future works. The first limitation concerns the choice of the users for the user tests. Although the users involved in the user studies usually come from ``technically sound'' domains (e.g., engineering students, researchers in the computer science domain, etc.), they only partially represent the real population. Especially for the Industry 4.0 domain, the proposed systems have not been evaluated involving the real final users, that is, the technicians or operators who truly work in the factories or companies. A possible improvement would be to involve those operators to verify whether the collected results are still legitimate and consistent. Furthermore, it would be appropriate to involve a larger number of users than the one considered for this thesis, thus improving the statistical significance of the results. The second limitation is related to the absence of control tasks, that should be carried out to understand the usefulness, successes and failures of any proposed system. The third limitation regards the analysis concerning the impact of the FoV on the usability of tabletop and first-person shooter games. The different evaluations proposed in this Ph.D dissertation have only compared two specific devices (HoloLens vs Oculus DK2 and HoloLens vs Oculus Rift, respectively) and there is the possibility that the collected outcomes are strictly related to the employed hardware and they cannot be easily generalized to the VR and AR modalities. One possible improvement would be repeating the experiments using only a single device capable of displaying contents using both VR and AR technologies (a possible choice could be the HTC Vive Pro equipped with frontal cameras).