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Virtual Reality Applications for Public Health and Safety

By

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Declaration

I hereby declare that, the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

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Virtual Reality Applications for Public Health and Safety

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Public health and safety share a common goal: protect and improve the well-being of communities. Scientific literature shows that Virtual Reality (VR) technology can offer unique benefits in these domains on three levels: *individual*, *professional*, and *societal*. In healthcare, VR applications have been effectively employed for physical and cognitive rehabilitation, as well as in the diagnosis and treatment of mental health conditions by providing immersive, controlled environments that facilitate therapeutic processes and engagement of *individuals*. VR applications can support public safety and health *professionals*' education and training, making it more engaging, effective, and safer than traditional methods through immersive and interactive experiences. VR simulations can also recreate scenarios such as natural disasters, emergency evacuations, and the spread of pandemics to help administrators and decision-makers make informed decisions, thus improving health and safety at the *societal* level.

The broad scope of these fields of application makes the pursuit of universal solutions a challenging endeavor. Nevertheless, there are still several open problems related to instructional and interaction design in VR experiences, as well as virtual agent design, which is integral to simulating the social dynamics critical to real-world public health and safety scenarios. The identified challenges include the assessment of systems for navigation and communication with virtual agents within contextually relevant VR scenarios. There are also issues concerning the absence of standardized approaches for implementing adaptive learning strategies and frameworks for procedural knowledge transfer. Moreover, the effects of virtual agents' presence in VR applications on user behavior, and their potential to facilitate user performance in learning and training scenarios still need exploration. Finally, there are challenges concerning the design of virtual agents and scalable behavioral models in simulations involving large groups of virtual humans. In summary, the main objective of this thesis is to explore and evaluate design approaches for VR applications and virtual agents that allow for the development of more effective VR solutions for public health and safety at the *individual*, *professional*, and *societal* levels, addressing two main research questions:

- **RQ1:** *Which design approaches can be leveraged to improve the effectiveness of VR applications for public health and safety?*
- **RQ2:** *How can virtual agents be used to improve the effectiveness of VR applications for public health and safety?*

The objective will be pursued by selecting one or more specific use cases for each of the three levels. The first use case, aimed primarily at *individuals*, explores a VR implementation of the Stroop test, examining the effects of competitive and collaborative agents on user performance. This investigation provides insights into the facilitating effect in cognitive tasks provided by virtual agents but also highlights the potential drawbacks of introducing competitive elements, such as increased stress and lower sense of control, contributing to the answer of both RQs.

Then several *professional* training use cases are presented. A survey on Virtual Patients (VPs) highlights many open areas of research, concerning both the design of VPs as well as the applications where they are featured, thus addressing both RQs. A VR firefighter training application is used as a testbed to compare three different locomotion systems. Findings help answer RQ1 as they suggest that low-fidelity systems can outperform high-fidelity ones in terms of usability and performance on tasks if the technology fails to meet expectations of naturalness. A user study conducted with a Difficult Airway Management training application highlights challenges in evaluating adaptive learning strategies, as well as potential pitfalls in the implementation of virtual instructors, addressing both RQs.

Finally, at the *societal* level, two city-scale Agent-Based Models that simulate complex crowd dynamics in crisis scenarios (natural disasters and pandemics) highlight the importance of scalable and realistic agent behaviors in VR simulations, addressing RQ2.