An AI and virtual reality-based computational model to simulate olfactory responses: proposing a research strategy

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Abstract. The combination of artificial intelligence and immersive technologies has the potential of enhancing olfactory experiences. This work proposes a research strategy for developing design guidelines for a computational model that integrates artificial intelligence and virtual reality technologies to simulate olfactory responses. We will follow the design science research approach, which will include a literature review, the development of design guidelines, and their evaluation. By leveraging machine learning algorithms and sensory data, the project seeks to optimize the perception and delivery of scents. The outcomes will contribute to creating more personalized and immersive olfactory experiences, potentially transforming industries such as perfumery and virtual reality.

1. Introduction

Integrating multiple sensory modalities into virtual reality (VR) and augmented reality (AR) environments is essential for creating immersive experiences. Among these, olfaction remains underexplored, despite its significant impact on perception and memory through its connection to the limbic system, enhancing realism and emotional engagement [1]. The complexity of incorporating olfaction in VR/AR lies in the precise control needed over scent delivery, timing, and intensity to match visual and auditory stimuli. Traditional methods have struggled with these demands, creating a gap in fully integrating olfaction into immersive systems [2].

Advanced AI techniques can contribute to dynamic, context-sensitive scent generation that adapts to user environments and interactions in real-time [3]. An AI model might leverage multimodal data inputs, including visual and auditory cues, user physiological responses, and contextual information, and machine learning algorithms can be used to predict and adjust scent profiles dynamically. Potential AI approaches include deep reinforcement learning for real-time adjustments and generative adversarial networks (GANs) for creating synthetic olfactory experiences based on user interaction patterns [4].

In this context, this work proposes a research strategy for developing design guidelines for a computational model that integrates artificial intelligence and virtual reality technologies to simulate olfactory responses, addressing current limitations such as scent accuracy, synchronization, and user-specific customization [5]. By applying machine learning algorithms and user interaction data, the system can contribute to enhance the immersive experience by dynamically predicting and adjusting scent profiles. This approach is promising to improve the technical performance of olfactory systems and open new possibilities in fields like entertainment, education, and therapy [6].

2. Method

This research project is part of the broader project “SOFIA: Sensorial Olfactory Framework Immersive AI” developed at the EMBRAPII Competence Center in Immersive Technologies Applied to Virtual Worlds (AKCIT). The study is exploratory, because research about immersive olfactory experience is recent, making exploratory studies a suitable approach [7]. Three senior researchers with expertise in AI, virtual reality, and olfactory sensory defined the initial research strategy, which we describe in the following sections for peer debriefing.

3. Proposed research strategy

The study adheres to the design science research (DSR) paradigm, which contributes to the advancement of knowledge, also addressing real-world applications related to the research problem or opportunity [8]. According to the DSR artifacts taxonomy, it will provide an artifact of type design guidelines, which uses constructs to represent a real-world situation or the design problem and its solution space.

The specific objectives of the study are (1) to characterize the state of the art and the state of the technique regarding the opportunities and challenges of olfactory sensory experiences based on VR and AI; (2) to integrate virtual reality and AI to simulate immersive olfactory experiences; (3) to design and develop design guidelines based on VR and AI to identify users' sensory perception in olfactory experiences; and (4) to demonstrate the validity of the developed guidelines through a proof of concept of users' sensory perception in olfactory experiences. The method will follow the six stages of DSR: (1) identify the problem; (2) define the objectives of the solution; (3) design and develop the guidelines; (4) demonstrate the developed guidelines; (5) evaluate the guidelines; and (6) communicate the results to the scientific community and the productive sector.

In DSR stages 1 and 2, the problem will be identified, and the objectives for developing immersive olfactory technologies will be established through a systematic literature review (SLR) in the scientific knowledge bases Scopus and Web of Science, in addition to a prospective study and review in the Clarivate patent database. As a foundation for a more comprehensive systematic literature review (SLR) and to gain an overview of the current state of knowledge, we conducted an exploratory review of existing literature reviews (umbrella review) on sensory technologies and their integration with immersive environments. We searched the Google Scholar for works published since 2020 using the keywords "augmented reality," "virtual reality," "olfaction," "state of the art," and "review," resulting in a total of 4,170 articles. From these, 12 articles were analyzed, out of which 8 were systematic reviews or state-of-the-art reviews, and the three most relevant were selected for detailed reading based on their relevance to our research problem. The exploratory review synthesized findings from multiple systematic reviews and meta-analyses, offering a broader perspective on the evolution of sensory technology and its application in immersive contexts. We present the preliminary findings on the Results section.

Then, for DSR stage 3, the new design guidelines will be proposed based on requirements identified by an exploratory interdisciplinary focus group composed of experts in AI, virtual reality, and chemistry. It will be developed using computational models of chemical structures, implemented in virtual reality simulation environments created on platforms like Unreal Engine or Unity, and integrated with sensory immersion devices such as advanced virtual reality headsets. Additionally, it will adopt elements identified in the state-of-the-art review, potentially using LLMs for odor selection, as large language models and generative models like Stable Diffusion are emerging as relevant tools in creating 3D environments emotionally connected to users [9-11].

The research will build on these developments by employing a multi-phase approach, beginning with the creation of a comprehensive dataset of scent profiles and their corresponding emotional and contextual associations [12]. This dataset will be used to train AI models capable of predicting the appropriate scent for specific scenarios within VR/AR environments. Machine learning techniques, such as supervised learning and reinforcement learning, will be applied to ensure the models can adapt to user preferences and real-time environmental changes [13].

In DSR stage 4, a proof of concept of the new guidelines will be demonstrated to the interdisciplinary focus group for validation and adjustments aimed at the functionality of the developed artifact. It will involve the integration of these AI models into a prototype olfaction system. This system will consist of a scent delivery mechanism capable of precise control over scent intensity and timing, synchronized with the visual and auditory components of the VR/AR experience [14]. The AI will dynamically adjust the scent profile based on user interactions and environmental cues, ensuring a seamless and immersive experience.

Stage 5 of the DSR will focus on evaluating the validity of the proposed guidelines. This evaluation will involve applying questionnaires based on the UTAUT2 model [15], which has been adapted to assess the acceptance of immersive technologies in sensory experiences. Additionally, the "Presence Questionnaire" (PQ) will be used to evaluate the sense of presence, a widely recognized measure in studies that assess the feeling of being present in a virtual environment [16]. The PQ covers aspects such as sensory realism, involvement, adaptation/immersion, and the possibility of acting within the virtual environment. Participants will rate their experiences on a Likert scale, allowing the quantification of the perceived level of presence. To further assess the effectiveness of the system, a series of user studies will be conducted [17]. Participants will interact with the VR/AR environments, and their responses to the olfactory stimuli will be measured through both subjective feedback and objective metrics, such as physiological responses. The collected data will then be used to refine the AI models, ultimately improving the system's performance [18].

In DSR stage 6, the findings will be communicated through scientific publications and conference presentations, highlighting the theoretical and practical contributions to the field of AI applied to immersive olfaction.

4. Results

The exploratory umbrella review aimed to identify key themes, gaps in the existing literature, and emerging trends that could inform the development of design guidelines for immersive sensory systems. The preliminary findings revealed several critical insights into the current state of olfactory technology in immersive environments. The review highlighted that while significant advancements have been made in sensory technologies and VR integration, there remains a substantial gap in the precise and dynamic simulation of olfactory experiences. The studies indicate that traditional scent delivery systems often struggle with synchronization and accuracy, which impacts the overall immersive experience [19][20].

Moreover, we identified emerging trends in the application of AI for olfactory simulations, particularly the use of machine learning algorithms to predict and adjust scent profiles based on real-time data [19]. This aligns with our proposed approach, which aims to address these challenges through advanced AI techniques and immersive technologies. The findings also underscored the potential for integrating large language models and generative models to enhance the realism and emotional engagement of olfactory experiences [20][21].

One notable trend is the increasing use of machine learning algorithms to enhance the accuracy and personalization of sensory experiences. However, a significant gap remains in the synchronization of scent delivery with visual and auditory stimuli, which impacts the overall immersive experience. These insights underscore the need for advanced AI-driven approaches to address these challenges and improve the integration of sensory technologies in immersive environments. Overall, the umbrella review has informed the development of our design guidelines by pinpointing key areas where innovation is needed and by validating the relevance of our proposed AI-driven approach to overcoming existing limitations.

5. Final Considerations

This research project aims to advance the state of the art in immersive olfaction systems by applying AI to overcome the existing challenges in scent delivery and synchronization within VR/AR environments. Our research is still in its early stages, and this work outlines our proposed strategies and shares preliminary findings from the exploratory review, inviting peer debriefing from the scientific community. By sharing these preliminary approaches, we seek to obtain valuable feedback and refine our methodologies for the next phases of the project. The successful implementation of such a system could have wide-ranging implications, not only for the entertainment and gaming industries but also for education, therapy, and other fields where sensory engagement is crucial. The anticipated contributions of this research include technical innovations in olfaction technology and new theoretical insights into the application of AI in multisensory integration.

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