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Research on Multi-Sensory Interaction Technology in Virtual Reality Environment

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Abstract. Multi-sensory interaction technology has a wide range of applications in virtual environments, covering a variety of fields such as urban planning, healthcare, education, etc., and demonstrating its potential for significant value in these fields. This paper reveals how multi-sensory interaction technology can enhance user immersion and interaction experience by simulating multiple sensory experiences through specific application cases. The purpose of this review is to integrate the research and applications of multi-sensory interaction technology in virtual environments from different fields in recent years. First, the paper details which sensory technologies have been integrated in different studies and what research results have been obtained from these studies. Moreover, the paper makes it clear that the sensory technologies most used in virtual environments are visual, auditory, and other sensory simulations. Although the sense of smell has begun to be utilized in some areas of research, it is still underdeveloped. As for taste interaction technology, it is still a relatively unexplored area in virtual environments. Most scholars mentioned in their research that with the continuous progress and maturity of technology, the application of multi-sensory interaction technology in virtual environments will be more extensive and in-depth. This will provide users with richer and more personalized experiences. This indicates that multi-sensory interaction technology has great potential for development in the future and will bring more innovation and change to virtual environments.

Keywords: Multi-Sensory; Virtual Environment; Systematic Review.

1. Introduction

Our perception and understanding of the world are achieved through the collaboration of multiple senses, including but not limited to vision, hearing, touch, smell, and taste [1]. These sensory information together form our comprehensive cognition of the surrounding environment. These sensory modalities work in harmony to provide us with a rich and comprehensive cognition of our surrounding environment. The interplay of these senses allows us to interpret and interact with the world in a meaningful way, forming the foundation of our experiences. Virtual reality (VR) systems utilize this fact by precisely simulating these sensory experiencefigs, providing users with a feeling of seemingly real existence. VR systems are capable of simulating visual, auditory, tactile, and other sensory feedback that matches the user's actions and the context of the virtual environment, thus creating a highly realistic immersive experience. The core of this experience lies in its ability to evoke a sense of "presence" in the virtual environment, making users feel as if they are truly part of that virtual world.

Multi-sensory interaction also plays a significant role in education and team collaboration [2]. Section 2.1 of this article will mention the support that multi-sensory interaction technology provides to online education. By integrating various sensory channels such as vision, hearing, touch, and proprioception, multi-sensory interaction strongly supports learning, inclusiveness, and collaboration. This form of interaction can meet the cognitive and perceptual needs of different individuals, making information transmission more efficient, learning experiences richer, and collaboration processes smoother. The process of merging visual, auditory, tactile, and proprioceptive sensory information into a unified experience is a cornerstone of effective learning and collaboration. It enhances the comprehensibility of information, making complex concepts more accessible and easier to grasp. Furthermore, it

improves the durability of memory, as the brain encodes experiences more effectively when multiple senses are involved. This multi-sensory integration also elevates user engagement, drawing learners into the educational content in a way that static, text-based materials cannot. The quality of interaction is heightened, as users can explore and manipulate virtual objects, engage in simulated scenarios, and collaborate with peers in a dynamic, sensory-rich environment.

The role of multi-sensory interaction in our perception of the world and its application in virtual reality and education cannot be overstated. It is a transformative force that is redefining how we experience and interact with our environment, both real and virtual. As technology continues to advance, the potential for multi-sensory interaction to enhance our lives and learning is limited only by our imagination.

2. Multi-Sensory Interaction Technology

To conduct a comprehensive analysis and summary of the included literature, this paper delves into the wide-ranging impacts of multi-sensory virtual reality (MSVR) applications. Through qualitative and quantitative research methods, this paper systematically analyzes the application effects of MSVR in various fields and assesses its potential benefits and limitations.

2.1. Application of Multi-Sensory Interaction Technology in Virtual Reality Environments Across Different Fields

In 2014, Julia Frohlich and Ipke Wachsmuth created a cave-like virtual reality environment and developed a complex multi-sensory display system for it [3]. This system integrated various sensory stimuli, such as visual, auditory, tactile, wind, and thermal sensations, to enhance the immersive experience of virtual reality (VR). The design was easy to integrate into existing or newly developed VR projects, and a software architecture allowed for the effortless addition of multiple sensory outputs. The device was known for its extensive multi-sensory display capabilities, characterized by low cost and a simple integration process. Through a user study, they assessed the system's impact on users' perceived presence and received positive feedback. This was considered one of the most advanced VR systems with multi-sensory display features at the time. The research outlined the potential and challenges of this technology, emphasizing considerations of safety, hardware, and software. It also evaluated different methods of delivering sensory stimuli and provided a detailed description of the comprehensive system they established in the laboratory. Technical assessments and user studies guided this development, identifying areas for improvement and potential opportunities (Fig. 1).

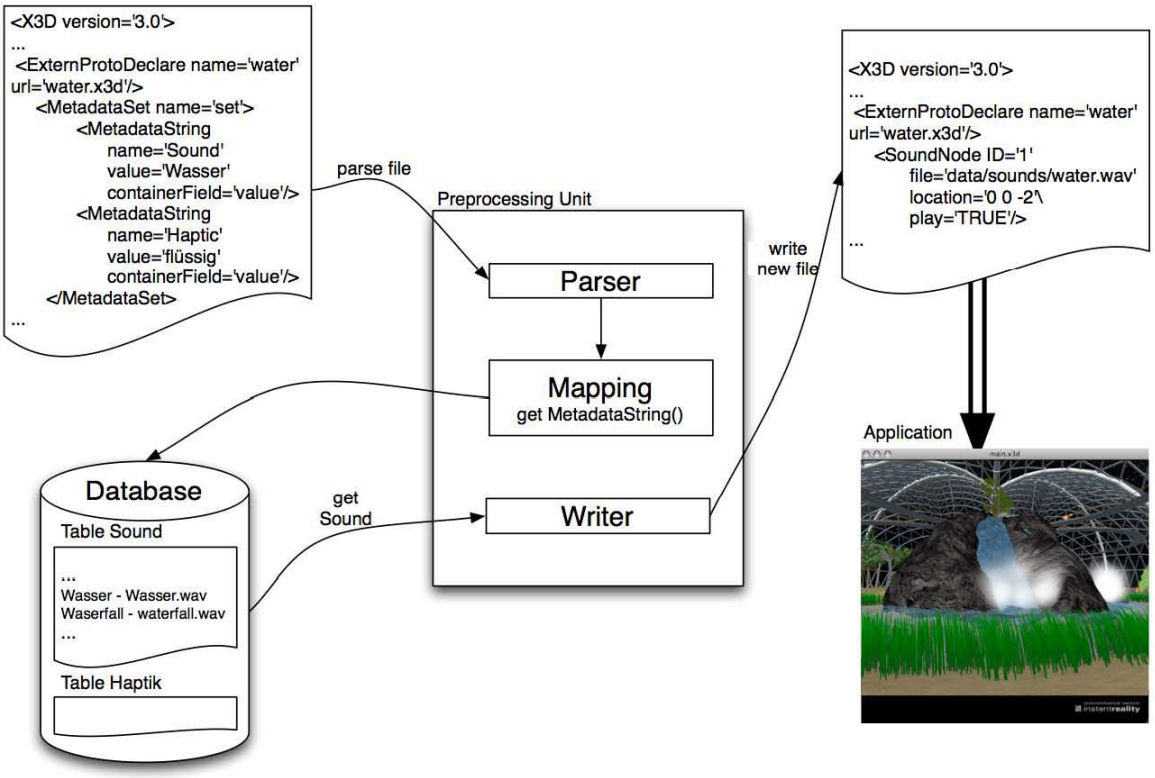

Figure 1. Concept of enriched virtual objects to create automated multi-modal feedback [3].

For a long time, researchers have been exploring a media technology that creates an immersive real or virtual world experience by replicating multiple sensory information. Surprisingly, two years after the research by Frohlich and Wachsmuth, Takuji Narumi's research has made significant progress, especially in the use of multi-sensory feedback technology through cross-modal interaction. Taking the "MetaCookie+" flavor enhancement system (Fig. 2) mentioned in Narumi's research as an example, people's cognitions of cookie flavor were altered by Narumi's superimposition of visual and olfactory information on real cookies. This innovative approach demonstrates the potential of multi-sensory feedback. In addition, the "augmented satiety" system is a solution that uses augmented reality and computer vision technology to change the visual volume of food, allowing us to effectively control satiety and food intake [4]. These studies show that through multi-modal VR technology, we have the ability to enhance the dining experience.

Figure 2. MetaCookie+: Presenting flavors through cross-sensory interactions involving vision, smell, and taste [4].

As multi-sensory interaction technology reveals its unique charm in various fields, Vanissa Wanick and others have introduced the concept of Virtual Transcendent Experience (VTE) into the research of multi-sensory environments. Furthermore, the Virtual Transcendent Experience Framework (VTE Framework, VTEf) further proposes a new concept and paradigm aimed at achieving this

transcendent sensation through multi-sensory technology. VTEf offers a thorough summary of the factors that shape the Quality of Experience (QoE) in immersive environments that rely on multisensory input [5].

In 2019, Dr. Glyn Lawson and his team developed a multi-sensory (MS) virtual environment (VE) that can provide corresponding thermal and olfactory experiences based on activities in the virtual world. Their overall goal was to explore how multi-sensory virtual environments can provide more engaging and effective training solutions through the integration of visual, auditory, olfactory, and thermal simulations [6]. This effort aims to address some of the current issues in health and safety training, such as the lack of engagement of trainees, the weak relevance of training content to actual work scenarios, and the mismatch of psychological states between the training environment and the target situation. The project successfully created a cost-effective multi-sensory simulator. The experimental research conducted in this environment is mainly divided into two parts. The first part of the study analyzed the behavioral differences between multi-sensory and audio-visual (AV) training simulators in the virtual environment, finding that multi-sensory simulation significantly improved the behavioral effectiveness of users in the virtual environment. The second part of the study focused on training outcomes, comparing virtual reality training with PowerPoint-based training, and allowing participants to experience both multi-sensory and audio-visual training modes. The research overall showed that virtual reality environments outperform PowerPoint-based training in terms of training effectiveness.

In recent years, as multi-sensory interaction technology rapidly develops and is widely applied in virtual environments across various fields, Sungchul Jung and his team achieved a new breakthrough in their research in 2020. They developed an experimental platform capable of providing users with multiple feedback modalities, including visual, auditory, floor vibration, wind, and olfactory sensations, representing the state-of-the-art technology worldwide at the time [7]. Prior to this, no technology had been able to offer such a diverse range of sensory feedback, and this was the first approach to investigate the confidence level of multi-sensory feedback responses in virtual reality.

Although multi-sensory interaction technology has been applied in many fields, its use in urban planning, particularly with intelligent digital tools such as immersive virtual reality (IVR), remains a relatively unexplored area. To address this gap, M Meenar and J Kitson focused on exploring the application of multi-sensory and multi-dimensional IVR technology in participatory planning. They organized four focus groups, allowing the members to experience three distinct forms of planning scenario presentations: the traditional two-dimensional video, the IVR simulation of immersive three-dimensional, and the four-dimensional multi-sensory IVR simulation that incorporates auditory and olfactory elements [8]. The research showed that compared to traditional 2D video presentations, IVR simulations significantly increased public engagement, the recall of planning scenarios, and the emotional response to design proposals. The conclusion pointed out that multi-sensory 4D IVR technology offers urban planners and policymakers a new way to enrich or complement traditional public participation processes. Additionally, the research not only enhanced the understanding of the role and its limitations of IVR in participatory planning but also contributed new scholarly resources to the field's development by integrating elements of multi-sensory, including visual, auditory, and olfactory cues, into IVR technology. However, additional investigation is essential to thoroughly examine the effects of olfactory cues within IVR simulations and to understand people's reactions to them. Despite the fact that the influence of smell on human decision-making is yet to be fully explored, it could potentially play a significant role in the engagement of citizens in the planning processes of smart cities.

In 2022, M Fiorentino et al. conducted a study aimed at validating the supportive role of the Multi-Sensory In-Store Virtual Reality Customer Journey (MSISVRCJ) in furniture sales, using virtual catalogs and product configurators [9]. This approach allowed customers to be fully immersed in a virtual environment. Sales experts could adjust the color, texture, and finish of the furniture, while customers explored different virtual environments. Additionally, customers had the opportunity to experience real tactile feedback through physical furniture samples available in the store.

In the same year, J Heyse et al. introduced an innovative research topic. Unilateral spatial neglect (USN), typically a consequence of stroke or acquired brain injury (Fig. 3), affects multiple sensory modes, leading to a failure to respond to stimuli on the contralateral side of space. Addressing this issue, J Heyse and teammates developed a system for applying Music Neglect Therapy (MNT) within a virtual reality (VR) environment. Compared to traditional rehabilitation methods, the application of VR in therapy demonstrates several advantages, such as the ability to modify treatment approaches and allow for more comprehensive data collection on treatment progress [10]. Patients respond to various sensory triggers within the VR environment, and the performance outcomes of clinical and non-clinical users can be clearly distinguished. Furthermore, patients indicated that the use of virtual reality improved their pleasure in the treatment experience. This research has made significant contributions to the current field of USN rehabilitation and this new tool is expected to complement existing rehabilitation methods.

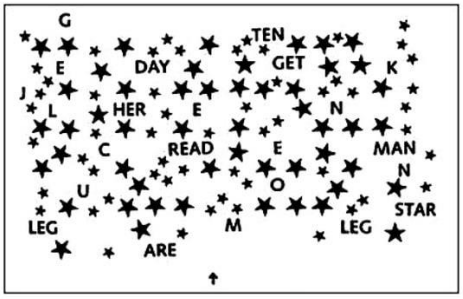

Figure 3. Star cancellation test requires marking all stars. Discrepancy in missed stars between sides may indicate USN [10].

Typically, people do not often associate sensory enhancement technologies with sustainable consumption. However, Tommi Laukkanen and his team have discussed sensory marketing enhanced by VR technology. They advocate the integration of virtual reality with various sensory enhancement technologies, such as wearable devices and body response technologies, in order to comprehensively grasp the impact of multisensory stimulation on consumers' choices and behaviors in sustainable decision-making [11]. They have demonstrated the cognitive and emotional benefits of virtual reality and have outlined strategies for leveraging VR technology to promote sustainable consumption patterns.

In 2023, the global situation of the novel coronavirus pneumonia began to show signs of improvement. During this period, online teaching models became more prevalent in response to the pandemic, and virtual reality online education is gradually emerging as a new trend in the future development of education. Building on this trend, WY Wu et al. optimized the output design of teaching information by investigating the effects of multi-sensory information displays on user cognition, aiming to allocate cognitive resources reasonably and ensure learning effectiveness [12].

3. Conclusion

Multi-sensory interaction technology has been widely applied in virtual environments, covering various fields and demonstrating its potential value. This technology integrates multiple sensory channels such as vision, hearing, touch, smell, and taste to provide users with a richer and more authentic interactive experience. In future research, we should consider how to achieve a deeper integration of different disciplines with interactive technology. For example, in the field of human-food interaction technology, multi-sensory interaction technology can not only change the flavor of food but also alter external information related to food, such as its color, shape, and texture, potentially enhancing our dining experience. Therefore, to further explore the application of multi-sensory interaction technology in food interaction, human-computer interaction research should be combined with fields such as cognitive science, psychology, and economics. Cognitive science can help us understand the cognitive processes and psychological changes of users during multi-sensory

interaction, psychology can study users' behavior and emotional responses, and economics can analyze the impact of multi-sensory interaction technology on the food market.

To date, visual and auditory stimuli remain the most frequently used forms of sensory stimulation in multi-sensory interactions. Although olfactory and gustatory stimuli were rarely used in the past, their development has gradually gained attention. The impact of olfaction and taste on human decision-making, especially in food selection and consumption decisions, has not been thoroughly studied. Therefore, more experiments are needed to investigate how olfaction and taste provide cues to people in virtual environments and how people respond to these cues.

Although olfaction and taste are crucial for virtual reality experiences, the characteristics of these stimuli and the equipment required to transmit them are often complex, expensive, and invasive. For example, special equipment is needed to simulate the texture and taste of food when stimulating taste. Therefore, it is necessary to conduct more in-depth research and development on the transmission of olfaction and taste and their impact on VR experiences. At the same time, researchers should explore ways to simplify the design of the equipment, reduce costs, and improve the portability and comfort of the equipment, so that more people can enjoy the convenience and pleasure brought by multi-sensory interaction technology.

In summary, the application of multi-sensory interaction technology in virtual environments has a broad prospect, but it still requires further research and development. By exploring the integration of different disciplines with interactive technology in depth, we can better understand the potential of multi-sensory interaction technology in various fields and promote its continuous development and improvement.

References

[1] Apostolou, Kalliopi, and Fotis Liarokapis. "A Systematic Review: The Role of Multi-sensory Feedback in Virtual Reality." 2022 IEEE 2nd International Conference on Intelligent Reality (ICIR). IEEE, 2022.

[2] Cho J D. Multi-sensory interaction for blind and visually impaired people[J]. Electronics, 2021, 10(24): 3170.

[3] Fröhlich, Julia, and Ipke Wachsmuth. "Combining Multi-Sensory Stimuli in Virtual Worlds–A Progress Report." Virtual, Augmented and Mixed Reality. Designing and Develop Virtual and Augmented Environments: 6th International Conference, VAMR 2014, Held as Part of HCI International 2014, Heraklion, Crete, Greece, June 22-27, 2014, Proceedings, Part I 6. Springer International Publishing, 2014.

[4] Narumi, Takuji. "Multi-sensorial virtual reality and augmented human food interaction." Proceedings of the 1st workshop on multi-sensorial approaches to human-food interaction. 2016.

[5] Wanick, Vanissa, Guilherme Xavier, and Erhan Ekmekcioglu. "Virtual transcendence experiences: Exploring technical and design challenges in multi-sensory environments." Proceedings of the 10th International Workshop on Immersive Mixed and Virtual Environment Systems. 2018.

[6] Lawson, Glyn, et al. "Immersive virtual worlds: Multi-sensory virtual environments for health and safety training." arxiv preprint arxiv:1910.04697 (2019).

[7] Jung, Sungchul, et al. "The impact of multi-sensory stimuli on confidence levels for perceptual-cognitive tasks in vr." 2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR). IEEE, 2020.

[8] Meenar M, Kitson J. Using multi-sensory and multi-dimensional immersive virtual reality in participatory planning[J]. Urban Science, 2020, 4(3): 34.

[9] Fiorentino M, Ricci M, Evangelista A, et al. A multi-sensory in-store virtual reality customer journey for retailing: a field study in a furniture flagship store[J]. Future Internet, 2022, 14(12): 381.

[10] Heyse J, Carlier S, Verhelst E, et al. From Patient to Musician: A Multi-Sensory Virtual Reality Rehabilitation Tool for Spatial Neglect[J]. Applied Sciences, 2022, 12(3): 1242.

[11] Laukkanen, Tommi, et al. "Virtual technologies in supporting sustainable consumption: From a single-sensory stimulus to a multi-sensory experience." International Journal of Information Management 63 (2022): 102455.

[12] Wu W Y, Guo J Y, Li Y J, et al. Research on the Design of Virtual Reality Online Education Information Presentation Based on Multi-Sensory Cognition[J]. Inventions, 2023, 8(2): 63.