Virtual Mixed Input Design

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1 Introduction

With the advancement of hand-tracking technology and new input modalities, digital drawing and design are not constrained to traditional methods with styluses or mouse-based interfaces anymore. The project investigates the effects of different VR input methods (hand-tracking and handheld controllers) on the art creation process within immersive virtual reality. The goal is to identify how each input method supports or hinders sketching and design in terms of comfort, performance, and user experience.

Hand-tracking allows for more natural and expressive interaction, much closer to real-world gestures. It may not offer the precision and fine control required for detailed drawing, however. VR controllers, meanwhile, offer more tactile feedback and consistent input but may not be as fluid or intuitive for creative work. This paper explicitly compares the two techniques by having users carry out constrained drawing tasks in VR using both input techniques and assessing drawing quality, usability, and task completion time.

Previous research presents contradictory impressions of hand-tracking use for virtual tasks. Hameed et al. [6] found that hand-tracking did not lead to a sense of greater presence, immersion, or naturalness, and that controller-based input led to faster task performance and reduced cognitive load. Similarly, Khundam et al. [8] found no differences in usability or satisfaction between hand-tracking and controllers in a clinical simulation. These studies did not, however, involve creative or artistic tasks, where both motor control and expressive freedom are crucial.

The trade-off between expressiveness and precision has been studied in other areas. Gesture interfaces have been shown to be effective intuitive substitutes for traditional HCI devices, though sometimes at the cost of response time or accuracy [7]. Rautaray and Agrawal [9] demonstrated that hand gestures provide improved natural spatial interaction, and Anthes et al. [1] illustrated how motion tracking contributes to immersion and expressiveness in virtual design and learning environments.

Arora et al. [2] explored freehand drawing in VR and found that orientation cues help improve placement accuracy, but can reduce line quality. These findings point to the challenge of drawing in mid-air without physical surfaces. This project compares two input modalities in a constrained drawing task to test which one is easier.

This research also contributes to ongoing discussions in digital creativity and immersive design. Guerra-Tamez [5] found that immersive VR can provide flow experiences for art and design students, promoting motivation, focus, and cognitive engagement. Their study relied on subjective self-reporting and did not examine how creative products are influenced by different input tools.

Candy et al. [3, 4] discuss that interactive technology changes art from its passive viewing to active creation and engagement. They advocate for systems facilitating expressive freedom and audience participation but cite the need for more applied research. Similarly, Singla et al. [10] proposed a touch-free sketching system using Leap Motion with good classification accuracy, while real-world testing is still limited.

Through explicit comparison of hand-tracking and controller input within the special case of 3D drawing, the project offers empirical findings on how the modality of input shapes virtual reality digital art creation. The findings are capable of informing future design of virtual creative tools and allowing virtual artistic creation to feel more natural, accurate, and fun.

2 Related Works

2.1 Hybrid Inputs

Huang et al. [7] research the blend of controller and gesture recognition as a hybrid input setup through the recruitment of users into a series of game-based activities in immersive surroundings. In noting that controllers as well as gesture-based inputs are widely utilized to interact in virtual spaces, the study aims to evaluate whether integration of the modalities could be used to optimize performance and interactive design. To search systematically in the hybrid input space, the researchers carried out three successive studies. The first was a design study aimed at determining what tasks intuitively suited hybrid interaction. From the results, they picked the top four-ranked tasks and deployed them for user testing. In the second phase, 22 participants used various

2.2 Motor Tasks: Hands vs. Controllers

Hameed et. al [6] examine the performance of hand-tracking compared to traditional handheld controllers for a reach-grab-place task in virtual reality (VR). A consumer-level VR headset, utilizing 33 participants, compared the two input methods on both objective task performance and subjective experience as measured by perceived presence, cognitive workload, and ease of use. To their surprise, hand-tracking did not significantly enhance the sense of presence, naturalness, or engagement. Instead, handheld controllers led to faster task performance and lower mental workload. These results go against the expectation of increasing more natural or immersive VR experiences through hand-tracking. Instead, results seem to suggest that handheld controllers may still have advantages of precision and usability for some tasks. This study contributes to a growing pool of literature questioning overly simplistic views of input "naturalness" and emphasizing the importance of context in designing for immersive interaction.

However, the research also identifies a few potential areas to investigate more deeply. The exercise was rather formal and functional, and it may have actually benefited accuracy and haptic sensitivity of controllers. Hand-tracking may still prove valuable in more open-ended, creative, or expression-oriented environments—such as that of digital artwork or body-led storytelling—where freedom of movement and fluidity of gestures is more a part of the engagement. Moreover, the current limitations of hand-tracking technology, i.e., fidelity of tracking, latency, and lack of haptic feedback, may have impacted user performance and experience. Future work could explore how hybrid input systems that combine the accuracy of controllers with expressiveness of gesture would obviate such limitations and support a wider range of immersive tasks.

2.3 Applying Immersion to Art Students, Flow Experience

Guerra-Tamez [5] presents a conceptual model investigating the impact of virtual reality (VR) on learning performance among undergraduate students of art and design. Using data collected from 200 participants through surveys, and analyzed through partial least squares structural equation modeling, the study concludes that immersive VR positively impacts students' flow experience. Such flow, in turn, enhances learning through motivation, curiosity, cognitive effort, reflective thinking, and perceived value. The findings suggest that VR could be an effective tool for enriching learning experiences in art and design subjects.

While its contribution is positive, the research leaves much work undone. It relies primarily on self-reported data from surveys, which can limit the objectivity of its results. In addition, although the model detects a positive relationship between VR and learning in terms of flow, it does not explore the qualitative aspect of the resultant learning outcomes or how VR facilitates particular artistic or design competencies. Long-term retention of learning, skill development in practice, and the impact of various forms of VR content or interaction models upon creative processes in educational contexts are some of the areas that further research could investigate.

2.4 Development of Interactive Art

Chapter 2 by Candy et. al [3] examines the convergence of interactive arts, audience engagement, and experience design in public art and makes parallels with contemporary Human-Computer Interaction (HCI) practice. Through an exploration of how audience experience is cycled back into artistic intention and interactive system design, the chapter introduces new research frameworks developed through practice-based approaches. Through the deployment of case studies and open questions, it creates a more complex vocabulary for explicating interactive experiences, offering worthwhile insights for HCI and digital art communities alike.

While the chapter raises very important questions and presents promising paths, there are certain areas needing further research. The discussion remains largely conceptual and lacks empirical proof or comparative analyses of different strategies of engagement. Additionally, although it suggests a more advanced vocabulary for discussing interaction, it does not completely address how these vocabularies transfer across different audiences or cultures. Additional studies could enhance the impact by incorporating more varied case studies, user-focused evaluations, and longitudinal information to explore how these frameworks influence both creative outputs and user experiences over time.

2.5 Engagement and Experience in Past Human Computer Interaction

Chapter 1 by Candy et al. [4] discusses the growing significance of interactive experience in contemporary digital art, putting into focus the shift from passive art consumption to active, participatory engagement made possible by digital technologies. The chapter explains how designers and artists are integrating evaluation into their design process using new methodologies to measure and assess interactive experience. It also situates the development of interactive digital art within the broader context of Human-Computer Interaction (HCI) and the Digital Arts, offering new paradigms for understanding and evaluating the evolving nature of interactive art.

However, while the chapter offers valuable information on how to incorporate evaluation into the creative process, there are several areas that require further investigation. The chapter's overview of evaluation methods remains unclear since it does not provide examples and empirical evidence of the proposed methods. Moreover, while providing so many new methods for evaluation, it does not explain the process of practical testing and improvement of these methods in real-world settings. Future studies could substantiate the chapter by providing case studies or comparative studies that document the effectiveness of these strategies on different kinds of interactive art and different audiences.

2.6 2D Rendering Using Hand Gestures

Singla et. al [10] present a method for designing touchless user interfaces using a Leap Motion controller to facilitate 2D and 3D shape drawing on display devices. By finger tracking and analysis using extended Npen++ features in 3D, the system maps natural gestures to shapes with a 92.87% classification rate. The technique, tested on a 5400 sample dataset, performs well with larger 3D features than traditional methods. The technique opens the door for developing new human-computer interaction (HCI) applications for smart devices, e.g., for physically disabled people.

While the paper demonstrates a nice approach to touchless interaction, there are some dimensions that should be looked into. The training data, although large, is limited to 10 volunteers and may fail to account for the range of hand sizes, gestures, or dexterity of the general population. The system's performance in dynamic real-life environments, where factors such as lighting or background noise could affect accuracy, is also not fully addressed. Future work can explore larger and more diverse datasets, as well as evaluating the system in other uncontrolled settings to identify the system's robustness and scalability for broader HCI applications.

2.7 Sketching in VR

Arora et. al [2] examine the challenges of drawing in interactive 3D virtual reality (VR) environments, namely the impact of the absence of a physical surface on which to place the stylus. Through controlled studies comparing drawing on a physical surface and drawing in VR, the authors conclude that the absence of a physical drawing surface significantly affects precision, and that the factor of orientation plays a significant role. A second experiment evaluates the role of visual guidance on accuracy, showing that while it aids positional accuracy, it is counterproductive to the aesthetic quality of strokes. The paper concludes with design guidelines for improving sketching tools in virtual reality environments.

While the study provides valuable insight into the tough problems of VR sketching, there are several areas that would benefit from further development. The experiments focus predominantly on positional accuracy and aesthetics but do not explore other dimensions such as user comfort or long-term usability of the VR sketching tools. Additionally, the study is limited by the range of VR environments and tools being tested, not taking into account how sketching precision will be influenced by different VR platforms or input methods. Subsequent studies can elaborate on experimenting with a greater range of VR systems, including different input devices and more diverse groups of users, to evaluate how these factors influence sketching performance and overall user experience.

2.8 Interaction Time and Usability (Hand Tracking vs Controllers)

Khundam et. al [8] study the comparative effectiveness of hand tracking and VR controllers in a virtual reality (VR) intubation simulation training for medical students. 30 participants were divided into two groups under quasi-experimental conditions to compare user interaction time, usability, and satisfaction using both types of input for seven procedures. The result indicated no statistically significant difference in interaction time, usability, and satisfaction in using controllers and hand tracking. The study concludes that hand tracking, which is more intuitive and natural, is equally good as controllers for VR medical training, and can be an excellent input mechanism for posture correction and self-learning improvement.

Although the study provides very valuable information about comparability of hand tracking and controllers for VR medical training, some areas might be further studied. The 30-subject population may be insufficient to allow variation in user preference or experience. Further, the experiment only addresses short-term usability and satisfaction rather than long-term learning retention or adaptation of users to other input modalities in the long run. Other research would include longitudinal studies to determine hand tracking effectiveness on skill retention and its impact on medical training performance in more complex, real-world environments.

2.9 Remote-Free Hand Tracking

Anthes et al. [1] provide a comprehensive review of virtual reality (VR) technology innovation with the advent of remote-free hand tracking as a natural and efficient type of human-computer interaction. The paper discusses several applications where hand tracking enhances immersion, control, and communication and presents a feasible alternative to traditional input devices like gloves, sensors, and controllers. The authors indicate the limitations of such conventional devices and suggest that direct hand movement is capable of revolutionizing VR to the extent that users can interact with virtual objects naturally without the need for supporting devices. This work is an early foundation for realizing the potential of hand tracking to improve immersive virtual spaces. While the paper offers valuable perspectives on the potential of hand tracking for VR, its discussion may be limited by the rapid progress of VR/AR technology development after publication. The study focuses mainly on theoretical benefits of hand tracking and fails to discuss latest hardware and software developments that could further enhance its efficiency. Additionally, the work does not take into account users' preference between traditional controllers and remote-free hand tracking in real-world use. Future work could build on this work by conducting empirical experiments comparing the two input modalities, examining user comfort, accuracy, and immersion, and incorporating modern VR technologies to examine their impact on user experience and performance in a variety of applications.

2.10 Evolution of VR, HMDs, and Input Devices

Rautaray [9] is a survey of the new advance in virtual reality (VR) with a focus on the progress of hardware and input devices. The study emphasizes the advance in consumer hardware such as head-mounted displays (HMDs), haptic devices, controllers, and gesture-tracking devices. These advances have all contributed to actualizing the promise of VR in scientific and professional applications. It is also addressing chronic problems in VR technology, such as motion-to-photon latency and barrel distortion, and making glimpses about future solutions. This paper begins to explore the broader implications of VR and AR, particularly for creative industries like art, which can enable geographically and socio-culturally bridging by these technologies.

While the paper provides a general overview of current VR technological advancements, it primarily focuses on hardware innovation without further exploring the tangible implications of these technologies in creative and artistic fields. It does not delve deeply into how these innovations can impact such fields as art creation, especially among non-VR/AR experts. Besides, while the paper discusses the potential for closing global gaps, it does not address how different cultures and nations can interact with or embrace such new VR technologies to the ends of art. Further research could explain how VR/AR can be utilized to foster cross-cultural artistic collaboration and how emerging technologies can popularize art-making for the non-technical crowd.

3 Methodology

3.1 Participants

Eight undergraduate participants participated in this research. Even though participants had varying academic majors, the majority of them were majors in computer science. Participants took part on a voluntary basis and as part of a class experience to collaborate with new creative technologies in a research setting. Participants were neither paid nor provided any incentives. Participant ages mainly varied between 18- to 22-year-olds. Demographic data were collected in simplified form, including each participant's field of study and year of study, since factors such as academic background and experience level might influence usability and performance perceptions. The experiment focused on within-subjects, with all participants completing all experimental conditions.

3.2 Apparatus

The experiment was conducted using the Meta Quest 3 virtual reality headset. Participants used a specially created virtual drawing software program for this study. The program allowed participants to draw anywhere in 3D space with reference sketches, and input logging and task timing were supported in real-time. Two input configurations were attempted: (1) the standard pair of Quest 3 controllers and (2) the native hand-tracking of the headset.

A custom created drawing program was made for the experiment using Unity, in which participants could draw anything freely in 3D space and view reference images for every task.

3.3 Procedure

The subjects were asked to re-draw three sample drawings that progressively increased in difficulty. The first consisted of simple geometric shapes, the second included overlap and curved shapes, and the third represented a more complex abstract line drawing. All of the drawings were accomplished with both input devices—hand and controller—so the subjects completed a total of six drawing tasks. The total time taken by each participant to complete each drawing was manually recorded by the experimenter.

The usability of the input device was also rated by the participants after every drawing on a 5-point Likert scale from "Very Uncomfortable" to "Very Comfortable." The drawings produced were also analyzed by the researcher based on similarity to the reference image in structure, proportion, and line quality.

Break times were offered among input conditions in order to break up fatigue. Upon completing all drawing tasks, participants completed an exit survey recording which input mode they most liked overall and adding a brief statement of their reasons, providing qualitative data on user experience and satisfaction.

3.4 Design

The experiment consisted of a 2×3 within-subjects design. Independent variables included:

- **Input Type**: Controller, Hand Tracking
- **Task Complexity**: Simple, Moderate, Complex

Both subjects did all combinations of the conditions. The dependent measures were:

- **Ease of Use**: Self-ratings of comfort for each input condition
- **Drawing Accuracy**: Evaluated by the researcher based on similarity to reference image
- **Completion Time**: Recorded by the researcher using a stopwatch

This design allowed for the analysis of both the main effects (e.g., which input method was simpler to rate) and interaction effects (e.g., whether task complexity was differentially affecting performance depending on input method).

4 Results and Discussion

5 Conclusion

Our experiment suggests that

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