Where Should a Virtual Guide Stand in a VR Museum?

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Abstract. In VR museums, where virtual guides play a key role, optimizing their position is critical to enhancing user experience. This paper models the location relationship between relic, visitor and virtual guide through user studies, and introduces the Asymmetrical Mutual Virtual Retargeting (AMVR) method, which addresses challenges related to visual occlusion and multi-user sensory inconsistency. AMVR uses a unique virtual retargeting technique applied to both users simultaneously. The method redirects each user's gaze to the other's guide, while confusing the direction of view and body orientation, so that each user believes everyone is looking at their guide. This approach optimizes the guide's position based on the differing locations of users, resulting in asymmetrical rotational gains during retargeting. By improving the spatial interaction between users and virtual guides, AMVR ensures smoother, more comfortable navigation while maintaining consistent guide presence for all users. Two user studies conducted to evaluate the method demonstrated significant improvements in task efficiency and user satisfaction, particularly in reducing occlusion and enhancing the perception of the consistent guide. Questionnaire results showed AMVR did not increase user discomfort and provided a more intuitive experience compared to other methods. AMVR offers a promising solution for optimizing multi-user interactions in VR museums, providing a strong basis for future research in virtual human-computer interaction.

Keywords: Virtual guide · Rotational gain · Virtual retargeting

1 Introduction

Virtual Reality (VR) museums [16,17] are revolutionizing the way cultural artifacts are exhibited, utilizing 3D visualization and interactive technologies to create immersive digital spaces. These virtual institutions offer a unique platform for the curation and dissemination of cultural heritage, providing global audiences with unparalleled access to historical and artistic collections. By fostering a deeper understanding of cultural legacies, they break down physical barriers

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and offer innovative ways to engage with our shared heritage. Virtual museum guides, interactive digital avatars, are central to enhancing the visitor experience within these VR environments, leveraging augmented and mixed reality technologies to deliver personalized, immersive tours [8,12,15]. These guides enrich cultural exploration by offering tailored educational content and narratives, making virtual museums more accessible and inclusive, particularly in overcoming interpersonal alienation [11] and physical limitations [1]. This expanding role of virtual guides in digital display and cultural education signals a growing focus on museum informatisation and the future of heritage interpretation.

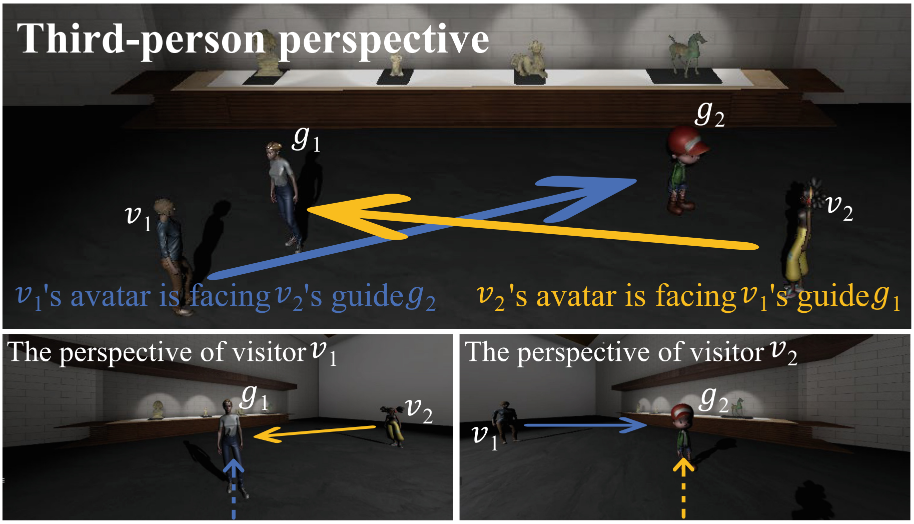

Fig. 1. A schematic representation of the inspirational concept behind the proposed method. The top panel shows the spatial arrangement of two visitors and their respective virtual guides from a third-person perspective. The bottom panels depict each visitor's view: v_1 and v_2 can only see their own guides (g_1 and g_2), preventing visual occlusion. Interestingly, from each visitor's perspective, it appears that the other visitor is looking at their own guide.

Despite advancements, there remains a significant gap in research focusing on optimizing user comfort and natural interaction in virtual museum environments [5,18]. Most current studies emphasize the technical implementation and preliminary user evaluation of virtual guides, often overlooking critical factors that affect overall user experience. For instance, Sylaiou et al. [18] explore the emotional impact of virtual avatars but devote limited attention to practical aspects such as guide positioning, pacing, or interaction tone. Similarly, De Carolis et al. [5] focus on usability, with little consideration for subtler interactions that could enhance user comfort. Ensuring that virtual guides not only deliver accurate and engaging content but do so in a manner that feels seamless and unobtrusive is key to creating an optimal user experience. This shift in focus requires deeper research into the subtleties of human-virtual guide interaction, emphasizing comfort and ease of use alongside technological advancement.

To address these gaps, this study introduces a novel method based on Asymmetrical Mutual Virtual Retargeting (AMVR), designed to improve the spatial relationship between the tour guide and the user, ensuring a more comfortable and intuitive experience. Our approach tackles the occlusion problem inherent to multi-user environments by making each visitor's tour guide visible only to them. Additionally, we address perceptual inconsistencies by implementing rotational gain, whereby each user's sightline subtly redirects its orientation toward the other guide when the user looks at their own guide (Virtual Retargeting). This mutual retargeting process is applied asymmetrically, reflecting the different positions and orientations of the users.

We formalize this problem and propose a feasible solution, evaluating our approach through two controlled user studies. The results demonstrate that our method significantly reduces occlusion, enhances the efficiency of information acquisition, and minimizes perceptual inconsistency compared to existing approaches. Figure 1 illustrates how the AMVR method operates: each visitor sees only their own guide, preventing visual occlusion, while perceiving that all other visitors are similarly engaged with their own guides. This design ensures a seamless and coherent user experience, free from informational clutter.

The contributions of this paper are summarized as follows:

- We introduce a method for generating tour guide positions that prioritize user comfort and spatial coherence, providing a reference for VR museum guide systems.
- We propose an optimized Asymmetrical Mutual Virtual Retargeting method, enhanced by rotational gain, that improves the efficiency of information retrieval and ensures cognitive consistency across multiple users.

2 Related Works

The expansion of VR technology has introduced a new paradigm in museum experiences: the virtual museum. These digital spaces utilize 3D visualization and interactive technologies to offer immersive exhibitions of cultural artifacts, granting global audiences unprecedented access to historical and artistic collections [16,19]. Within this framework, the virtual museum guide has emerged as a critical feature [3], enhancing visitor experience through personalized tours within virtual environments. These interactive avatars leverage augmented and mixed reality to deliver educational content in an immersive manner [8,15].

While research on virtual museum guides has grown, much of it remains focused on technical aspects, such as natural language processing, 3D avatar modeling, and AI integration for responsive behaviors [5,14]. Although these advancements are essential for functionality, they often neglect subtle yet crucial elements of user experience that define comfort and engagement. Current studies frequently emphasize the accuracy of information delivered by virtual guides [20], yet place less focus on how this information is presented to maintain an organic and unobtrusive visitor experience. Key areas requiring further investigation include the spatial relationship between guide and user, guide positioning and orientation, and adaptability to user preferences and behaviors. Sylaiou et al. [18], for example, explore the emotional impact of avatar personas in virtual museums, shedding light on the affective potential of virtual guides, though overlooking how positioning influences user comfort and immersion. Similarly, De Carolis et al. [5] examine virtual agents for museum navigation with an emphasis on system usability, but give limited attention to critical user-guide interactions, such as optimal positioning, distance, tone, and speed for a comfortable user experience.

These gaps are especially evident in multi-user environments, where challenges like visual occlusion and inconsistent perception of virtual guides are more pronounced. Existing technical solutions often lack consideration of broader implications for user comfort and experience quality. In light of these issues, a need exists for research prioritizing the nuanced dynamics of human-virtual guide interaction. Specifically, examining guide positioning, visibility, and behavior is essential to enhance comfort, naturalness, and user experience consistency. Addressing these factors will ensure that advancements in virtual museum guides are informed by a deep understanding of user needs and behaviors, promoting a more accessible and inclusive cultural experience.

3 Method

This section outlines the methodology employed in our research, from the initial pilot study through to the implementation of the Asymmetrical Mutual Virtual Retargeting (AMVR) method. The approach was designed to optimize the spatial positioning of virtual guides and enhance the overall user experience in multi-user virtual environments.

3.1 Pilot Study on Optimal Tour Guide Positioning

In the quest to determine the optimal positioning of virtual guides within a VR museum, we embarked on a comprehensive pilot study. The aim was to understand user preferences regarding the relative positioning of virtual guides, users, and cultural relics, ultimately modeling the spatial relationships between these entities.

Objectives and Hypotheses. The primary objective is to determine whether the virtual guide should be positioned with a focus on the user or the cultural relics. Moreover, according to Dr. Edward Hall's theory of proxemics [6,7], the social distance is delineated as ranging from 4 to 12 ft, which is approximately 1.2 to 3.7 m. This range is typically appropriate for more formal social contexts.

The interaction between a tour guide and tourists, while not always formal, often involves the conveyance of information and a degree of social interaction. Therefore, 1.2 to 3.7 m may be a reasonable distance between the virtual guide and the visitor. This distance can not only respect the personal space of tourists and make them feel at ease, but also enable tour guides to ensure the effective transmission of information and improve the interactive effect. We formulated the following hypotheses:

H0-a. Visitors are more inclined to the virtual wizard should focus on the user.

H0-b. A reasonable distance between the virtual guide and visitor is 1.2 to 3.7 m.

In order to validate these hypotheses, we designed an experimental device to systematically change the direction of the virtual tour guide and the distance from the visitor.

Experimental Setup. The virtual guide was positioned at varying angles and distances to simulate different interaction scenarios. We varied the position of the virtual guide across different angles (0°, 15°, 30°, 45°, etc., up to 180°) and distances (1 to 4 m) with the visitor v placed at a fixed point, as shown in Fig. 2 (a). This setup allowed us to simulate various interaction scenarios and assess user comfort and interaction dynamics with the virtual guide in relation to the cultural relic r. A total of 20 subjects participated in the pilot study. Participants were asked to interact with the virtual environment while the guide was positioned at each of the predetermined angles and distances. Their comfort level, ease of interaction, and overall experience were assessed through a combination of direct feedback and observational analysis.

Results and Analysis. In the course of the experiment, users without exception require virtual tour guides to face themselves, rather than cultural relics or other directions. They also do not pay attention to the relationship between virtual guides and cultural relics, The results support **H0-a**. The experimental results, as illustrated in Fig. 2 (b), revealed a distinct preference among users. The majority favored positions where the guide was angled at 15° or 30° relative to the user, indicating a preference for direct engagement rather than the guide's focus on the relics. Additionally, the preferred distances for the guide were found to be between 2 to 3 m, striking a balance between intimacy and personal space. This result supports **H0-b**.

Optimal Positioning Area. Based on the collective data, an optimal positioning area was identified, as depicted in Fig. 2 (c). We abstract the relationship between the cultural relics r, visitors v, and the tour guide g into three-tuple (r, v, g). This area, denoted as region A, represents the most favorable positions for the virtual guide g in relation to a single user. The corresponding axisymmetric region A', relative to the user-relics axis rv, solidifies the guide's positioning strategy for an enhanced user experience, and, being in the same situation as A, can also serve as an alternative region.

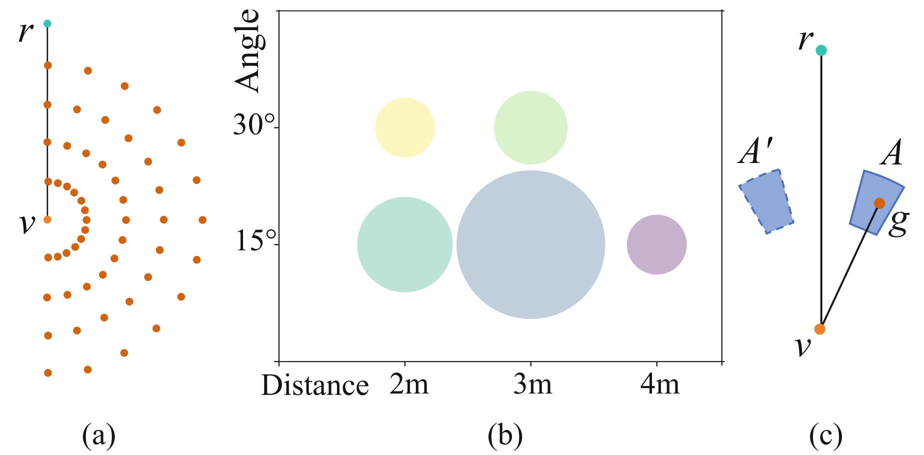

Fig. 2. (a) The experimental design, (b) The experimental results, and (c) the foundational relationship model inferred from the pilot study.

3.2 Guide Positioning and Visibility in Multi-user Environments

The intricacies of virtual tour guide positioning escalate in scenarios with multiple users and their respective guides. This section delves into the challenges and potential solutions for maintaining an effective and non-disruptive guide presence in a multi-user virtual environment. The most critical is the visibility and consistency of virtual guides when multiple users share the same space. We aimed to mitigate the risk of visual obstructions between guides and to ensure a seamless user experience. Figure 3 simulates a multi-user environment where each user is accompanied by a virtual guide. The setup involved two users, v_1 and v_2, each with their guide, g_1 and g_2, positioned in proximity to a central cultural artifact r.

A critical issue arises when the guide intended for one user obstructs the view of another user's guide, as depicted in Fig. 3 (a). Here, the line of sight from v_2 to r is obstructed by g_1, potentially disrupting the experience for v_2. One solution is to render the guide visible solely to its designated user, thus avoiding obstructions. However, this introduces a new challenge: perceptual inconsistency. As shown in Fig. 3 (b), v_2 perceives g_2 but not g_1, which is invisible. When g_1 delivers a presentation, v_2 may notice v_1 facing an empty space, causing confusion. This inconsistency is quantified by the angle γ between $v_1 g_1$ and$v_1 g_2$.

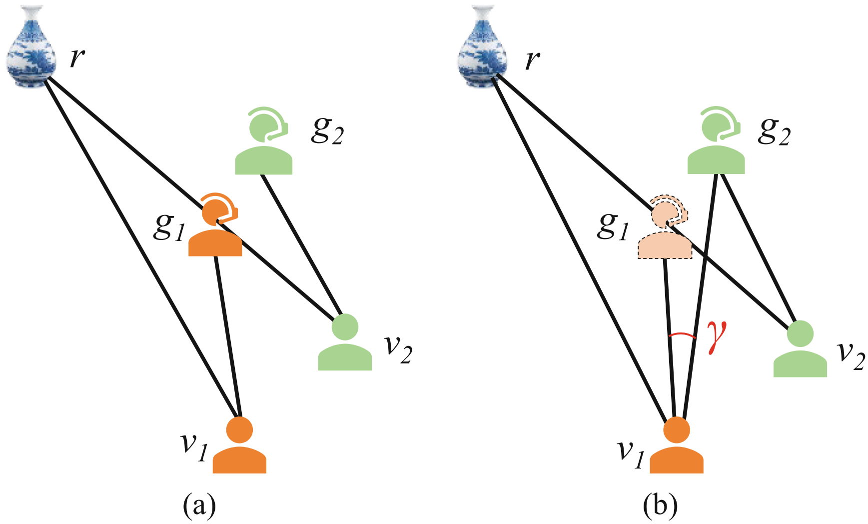

Fig. 3. (a) Demonstrates the occlusion issues that basic methods may encounter in a multi-user environment, (b) A method to reduce occlusion by concealing guides of others, which, however, may lead to cognitive inconsistencies.

3.3 Asymmetrical Mutual Virtual Retargeting for Multi-user Consistency

To address the challenges of guide visibility and user orientation in virtual environments, we introduce an innovative virtual retargeting method that employs an enhanced rotational gain. This method is designed to align the user's viewpoint with their respective guide while simultaneously aligning their body orientation towards the other user's guide, thereby creating a consistent perceptual experience for all parties involved.

Figure 4 shows the basic idea of the proposed method in a possible case. In scenarios where visitors v_1 and v_2 are positioned at fixed locations, the guides g_1 and g_2 are constrained to specific appropriate regions, typically depicted in different colors for distinction. The proposed method leverages the concept of rotational gain to adjust the user's perspective and body orientation. When the user v_1 is attracted by the explanation of the virtual guide g_1, its line of sight turns from the cultural relics r to its own guide g_1, but its body turns from the cultural relics r to g_2. Therefore, from the perspective of v_2, the user v_1 is attracted by its own guide g_2, thus maintaining consistency. Visitor v_1 sees the same way, so as to achieve the effect that both sides feel that there is only one guide, that is, their own guide. At this time, the rotation gain of user v_1 is $k_1 = \beta_1/\alpha_1$, and the rotation gain of v_2 is $k_2 = \beta_2/\alpha_2$.

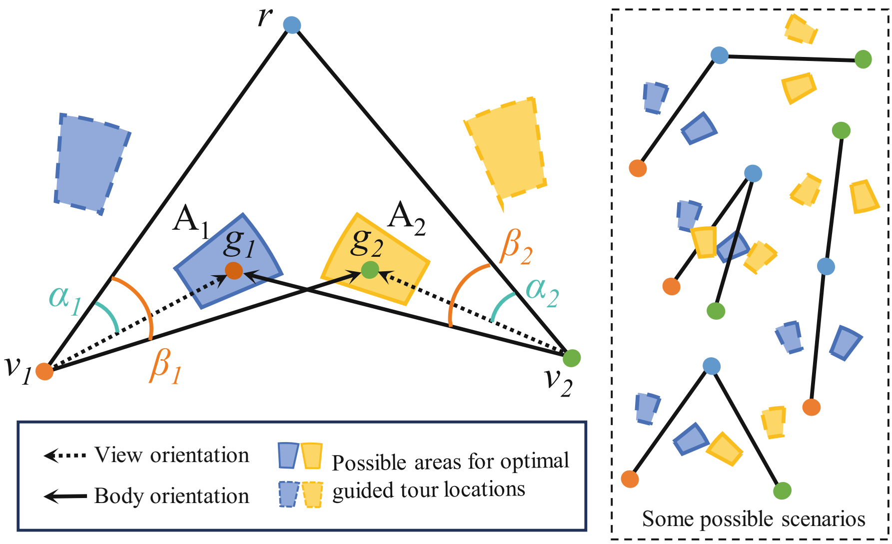

Fig. 4. A schematic diagram of the method

Although the retargeting of virtual objects can be completed by increasing the rotation gain, too large or too small gain ratio will cause the user's rotation speed to be too fast or too slow in the eyes of others, becoming unnatural and affecting the sense of immersion. Therefore, the optimal positioning of the virtual guides g_1 and g_2 is crucial to minimize the rotation gains $\|k_1-1\|_2$ and $\|k_2-1\|_2$, that is, the whole problem can be formalized as Eq. 1.

$$\begin{aligned} \text{minimize} \quad & F(g_1, g_2) = \omega_1 \times \|k_1 - 1\|_2 + \omega_2 \times \|k_2 - 1\|_2 \\ \text{subject to} \quad & g_1 \in A_1, \quad g_2 \in A_2, \end{aligned} \tag{1}$$

where ω_1 and ω_2 are weight coefficients, which are used to balance the importance of k_1 and k_2 in the overall objective function.

Indeed, there is a complexity of multiple scenarios for different users' stations and corresponding tour guide positions. According to the firstness principle, we adopt a straightforward yet effective strategy to find the optimal positions for g_1 and g_2. The goal is to make g_1 and g_2 as close as possible in their designated areas A_1 and A_2 to reduce the above angles, thereby minimizing perceptual differences.

We analyze the geometric relationships between the guides' positions by connecting the centers of their respective regions. We study the intersection of the line connecting these centers with the regional boundary and divide it into three different situations. When the line intersects two arcs in each region, the positions of g_1 and g_2 can be calculated by Algorithm 1. In cases where the line intersects two straight lines, the positions of g_1 and g_2 can be calculated by

Algorithm 2. The positions of g_1 and g_2 can be computed by the Algorithm 3 in the case where the centre line intersects one arc and one line.

Algorithm 1. Point Selection in the Case of Intersection with Two Line Segments

Input: Line segments SL_1 and SL_2
Output: Optimal points g_1, g_2

Calculate the distance between the endpoints of SL_1 and SL_2.
Choose the two endpoints that are closer in distance.
Draw perpendicular lines from the two endpoints to the other line segment.
if Both perpendicular points are on the line segments **then**
    Choose the shorter perpendicular segment ends as g_1, g_2.
else if One perpendicular point is on the line segment **then**
    Choose the ends of the perpendicular segment as g_1, g_2.
else
    Choose the aforementioned endpoints as g_1, g_2.
end if

Algorithm 2. Point Selection in the Case of Intersection with Two Arc Segments

Input: Arc segments AL_1 and AL_2
Output: Optimal points g_1, g_2

Connect the centers C_1 and C_2 of the arc segments to get the connection N.
if N intersects with both arcs **then**
    Calculate the two intersection points as g_1, g_2.
else if N intersects with only one arc **then**
    Connect the center of the intersecting arc with the vertex of the non-intersecting arc.
    Calculate the distance between the intersection point and the vertex.
    Choose the point with the smaller distance as g_1, g_2.
else
    Calculate the distance between the endpoints of the two arc segments.
    Choose the endpoint with the smallest distance as g_1, g_2.
end if

4 Experiences

We initially conducted simulations through automated experiments to preliminarily validate the estimations of occlusion and consistency for various methods. Subsequently, we designed a user study, which involved two tasks to confirm the advantages of the proposed approach.

Algorithm 3. Point Selection in the Case of Intersection with One Line and One Arc

```
Input: Line segment SL_1 and arc segment AL_2
Output: Optimal points g_1, g_2

Draw a perpendicular line from the center C_2 of arc AL_2 to line SL_1.
if The perpendicular point is on the line segment then
    Calculate the intersection point between the perpendicular line and the arc.
    Choose the intersection point and the perpendicular point as g_1, g_2.
else
    Calculate the distance between the line segment endpoints and the arc endpoints.
    Choose the endpoint with the smallest distance as g_1, g_2.
end if
```

4.1 Automated Quantitative Analysis

In this study, we conduct simulation experiments to meticulously evaluate the comparative merits and demerits of various methodologies. The experimental framework is structured around two distinct control groups. The **first control group (CG1)** employs the methodology delineated in Fig. 3 as method (a), while the **second control group (CG2)** adheres to the protocol outlined in the same figure as method (b). The **experimental group (EG)** used the proposed virtual retargeting method.

Probabilistic Analysis of Occlusion in CG1. Our analysis commences with a stochastic generation of two virtual tourists and their respective tour guides within a predefined environment. We establish connections between the tourists and the cultural artifacts, and subsequently ascertain the presence of tour guides along these linkages. This process culminates in the computation of the associated probabilities, which serve as a metric for the efficacy of the masking technique. After nearly 6000 simulations, **the average occlusion probability is 29.61%**. Since users cannot see other people 's guides, there is no occlusion in the EG method.

Quantitative Assessment of Inconsistency in CG2. To assess perceptual dissonance when a visitor observes another seemingly gazing into emptiness, we define 'inconsistency' as the angular discrepancy between the expected and actual gaze directions. This discrepancy is measured when the user's gaze aligns with the two guides, offering a quantifiable index of consistency. Experimental results show an **inconsistency of** $30.87°$. In contrast, the **EG** method eliminates inconsistency due to the effect of rotational gain.

4.2 User Study Settings

Overview and Hypotheses. We designed user experiments to validate the effectiveness of the methodology, encompassing three aspects: efficiency of information access, consistency perception, and comfort. Thus, we formulate the following hypotheses:
H1. It takes less time to finish the information access task with the AMVR method.
H2. The AMVR allows the user to feel that both parties are sharing a virtual guide.
H3. The AMVR method does not reduce user comfort.

Participants and Metrics. We have recruited 35 participants, 20 male and 15 female, between 18 and 35 years old. 6 of our participants had used immersive VR applications before. Participants had normal or corrected vision, and none reported vision or balance disorders. The participants were randomly assigned to two control groups and one experimental group. Task performance is measured by the following objective metrics: (1) **Correctness Rate**, defined as the ratio of the number of tasks completed correctly to the total number of tasks; (2) **Task completion time**, measured in seconds; and (3) **On-time Completion Rate**, the ratio of the number of persons who were able to complete their tasks within the specified time to the total number of persons. We also evaluated the proposed method in this paper by two subjective indicators: (4) **Occlusion rate**, the ratio of the number of people who felt they were occluded to the total number of people, and (5) **Agreement rate**, the ratio of the number of people who felt that they and another person were guided by the same guide to the total number of people. Still, we evaluated the VR experience with three commonly used questionnaires: (6) user task load, as measured by the standard **NASA-TLX** questionnaire [9,10], (7) user perception of the usability of the proposed methodology as assessed by the **SUS** questionnaire [2], and (8) user cybersickness as measured by the standard **SSQ** questionnaire [13].

For the time metric, the EG values were compared to CG1. The comparison was performed using a Mann-Whitney U Test Calculator. In addition to the p value of the statistical test, we also use Cohen's d [4] to estimate the effect size. Cohen's d is a standardized measure of the difference between two groups, indicating the standardized mean difference. In this text, the values of Cohen's d are translated into different qualitative estimates of effect size: Huge ($d > 2.0$), Very Large ($1.2 < d \leq 2.0$), Large ($0.8 < d \leq 1.2$), Medium ($0.5 < d \leq 0.8$), Small ($0.2 < d \leq 0.5$), and Very Small ($0.01 < d \leq 0.2$).

Task Design. We designed two tasks for the user study, Counting Circles on the Wall and Sphere Matching Task, as shown in Fig. 5. In the **first task (T1)**, subjects had to count how many circles were contained in a drawing on a wall from the number of circles contained in it within a time limit, as shown in Fig. 5(a). Tests were conducted in the same environment using different methods. When the counting is complete, the user and the guide are transported to a new random location to start the next round of counting. The size of the virtual environment is 5 m × 5 m. The user is located in the centre of the virtual environment and the painting is on one of the side walls. After several rounds of counting, the task is completed. The task examines the efficiency of the user's access to the overall information under different methods.

In the **second task (T2)**, a 32 cm diameter sphere was generated around the tour guide, while five different coloured spheres of the same size were generated near the wall, and participants had to locate the same coloured sphere and use the joystick to send out rays for pointing, as shown in Fig. 5(b). Again, the task was completed after several rounds of tapping. This task simulates the scenario of finding the corresponding content at the artefacts when the user receives some instructions or information from the guide.

Fig. 5. Schematic diagrams of the two tasks: Counting Circles on the Wall and Sphere Matching.

4.3 Results and Discussion

Table 1. Correctness rate results.

Task	Condition	Avg. ± std.dev.	p	Cohen's d	Effect size
Task1	EG	100 ± 0			
	CG1	93.8 ± 12.0	0.09	0.73	Medium
	CG2	95.0 ± 8.9	0.08	0.79	Medium
Task2	EG	99.7 ± 1.1			
	CG1	97.1 ± 4.2	0.01	0.86	Large
	CG2	98.9 ± 2.7	0.09	0.38	Small

Correctness Rate. Table 1 compares Task 1 and Task 2 results across the Experimental Group (EG) and two control groups (CG1, CG2). For Task 1, which assessed visual information processing by counting circles, EG achieved perfect accuracy (100 ± 0%), while CG1 (93.8 ± 12.0%) and CG2 (95.0 ± 8.9%) had lower rates, though not significantly different ($p = 0.09$ and $p = 0.08$), respectively. Effect sizes were medium for both CGs. In Task 2, involving locating a color-matched sphere, EG excelled with a near-perfect accuracy (99.7 ± 1.1%), significantly outperforming CG1 (97.1 ± 4.2%, $p = 0.01$, large effect size). CG2's performance (98.9 ± 2.7%) was closer to EG but not significantly different ($p = 0.09$, small effect size). Overall, EG showed higher accuracy in both tasks, with Task 2 demonstrating a significant advantage for the AMVR method used by EG, highlighting its effectiveness in complex tasks.

Task Completion Time. Table 2 shows the time (in seconds) taken by different groups to complete Tasks 1 and 2. For Task 1, EG completed the task in an average of **14.4 ± 1.5 s**, significantly faster than CG1 (**25.6 ± 6.0 s**, ($p < 0.001$), large effect size) and CG2 (**17.7 ± 3.5 s**, ($p < 0.001$), very large effect size), indicating AMVR's efficiency. In Task 2, EG again showed efficiency with an average time of **29.6 ± 3.7 s**. CG1 was significantly slower (**45.5 ± 9.8 s**, ($p < 0.001$), huge effect size), while CG2 was closer but still significantly slower (**32.9 ± 5.3 s**, ($p = 0.011$), medium effect size). Overall, the AMVR method (EG) significantly improved task efficiency in both tasks, with large effect sizes compared to both control groups, highlighting its facilitation of faster interactions in the virtual environment.

Table 2. Time taken to complete tasks, in seconds.

Task	Condition	Avg. ± std.dev.	*p*	Cohen's d	Effect size
T1	EG	14.4 ± 1.5			
	CG1	25.6 ± 6.0	<0.001*	2.59	Huge
	CG2	17.7 ± 3.5	<0.001*	1.25	Very Large
T2	EG	29.6 ± 3.7			
	CG1	45.5 ± 9.8	<0.001*	2.15	Huge
	CG2	32.9 ± 5.3	0.011	0.72	Medium

On-Time Completion Rate. Table 3 details the on-time completion rates for Task 1. EG achieved an on-time completion rate of **98.8 ± 5.0%**, demonstrating high consistency and effectiveness of the AMVR method in meeting time constraints. CG1 had a significantly lower rate at **45.0 ± 29.7%** (($p < 0.0001$), huge effect size), indicating substantial variability and inefficiency. CG2 outperformed CG1 with a rate of **88.8 ± 21.9%** (($p = 0.05$), medium effect size), but still fell short of EG's performance. The AMVR method in EG ensured nearly all participants finished Task 1 on time with minimal variation, significantly outperforming CG1 and providing a measurable advantage over CG2. These results support the hypothesis (**H1**) that the AMVR method enhances task efficiency, accuracy, and adherence to time limits.

Table 3. On-time completion rate results.

Task	Condition	Avg. ± std.dev.	p	Cohen's d	Effect size
T1	EG	98.8 ± 5.0			
	CG1	45.0 ± 29.7	<0.0001*	2.53	Huge
	CG2	88.8 ± 21.9	0.05	0.63	Medium

Subjective Perception. Table 4 shows user perceptions of obstruction and guide continuity. In EG, **90.32%** of users felt unobstructed and believed both avatars had the same guide, reflecting a strong sense of continuity with the AMVR method. CG1 had **75%** of users feeling obstructed, likely due to interference with information access, significantly affecting their experience. CG2, despite no obstruction reports, had only **9.09%** believe in shared guide continuity, indicating that visual obstructions alone don't define user experience. Overall, EG's AMVR method enhanced unobstructed interaction and guide continuity, while CG1's obstructions disrupted experience, and CG2 lacked coherent cues, supporting **H2**.

Table 4. Experimental results of users' subjective perception of being obscured and users' perception that the tour guide is the same person.

Condition	Feeling obscured	Believes both guides are the same person
EG	NOT obstructed	90.32%
CG1	75%	-
CG2	NOT obstructed	9.09%

Table 5. NASA-TLX Task Load Index data.

Task	Condition	Avg. ± std.dev.	p	Cohen's d	Effect size
Task1	EG	20.8 ± 13.3			
	CG1	20.0 ± 12.6	0.43	0.06	Very Small
	CG2	17.5 ± 27.8	0.33	0.25	Small
Task2	EG	30.9 ± 15.3			
	CG1	30.3 ± 25.0	0.36	0.03	Very Small
	CG2	30.8 ± 9.8	0.47	0.01	Very Small

NASA-TLX Task Load Index. Table 5 reveals no significant task load differences between EG and control groups across two tasks. In Task 1, EG's task load was **20.8** ± **13.3**, similar to CG1 (**20.0** ± **12.6**) and slightly higher than CG2 (**17.5** ± **27.8**), with non-significant differences ((p = 0.43) and (p = 0.33)). Task 2 saw nearly identical task loads across groups (EG: **30.9** ± **15.3**, CG1: **30.3** ± **25.0**, CG2: **30.8** ± **9.8**), again with non-significant differences ((p = 0.36) and (p = 0.47)). Overall, both tasks showed minimal variation in task load among groups, suggesting that while AMVR may offer benefits like reduced visual clutter, it did not significantly reduce perceived effort.

System Usability Scale Score. Table 6 shows that EG had significantly higher SUS scores for usability in Task 1 compared to both CG1 and CG2. In Task 1, EG scored **80.8** ± **5.6**, significantly higher than CG1 (**68.3** ± **14.6**, (p = 0.06), large effect size) and CG2 (**68.0** ± **23.3**, (p = 0.03), medium effect size). This indicates a substantially better user experience with the experimental method in Task 1, which involved counting circles. While Task 2 results were not detailed, they suggest that EG continued to show better usability, though with less dramatic differences. Overall, AMVR provided a significantly more user-friendly experience, particularly in simpler tasks like Task 1, and remained more usable in more complex interactions.

Table 6. SUS scores for methods in two tasks.

Task	Condition	Avg. ± std.dev.	*p*	Cohen's d	Effect size
Task1	EG	80.8 ± 5.6			
	CG1	68.3 ± 14.6	0.06	1.13	Very Large
	CG2	68.0 ± 23.3	0.03	0.76	Medium
Task2	EG	83 ± 6.7			
	CG1	75.4 ± 19	0.07	0.53	Medium
	CG2	70.7 ± 22.7	0.05	0.73	Medium

Simulator Sickness Questionnaire Score. Table 7 details Simulator Sickness Questionnaire (SSQ) scores, focusing on changes within each group. In Task 1, EG saw a slight, non-significant increase in sickness (from **4.5** ± **1.6** to **5.3** ± **1.8**, (p = 0.2)), while CG1 remained stable (**3.8** ± **1.1**, (p = 0.5)), and CG2 showed no further discomfort with constant scores (**7.8** ± **5.3**, (p = 0.5)). For Task 2, EG maintained stable sickness levels (**3.2** ± **0.4**, (p = 0.5)), CG1 showed a non-significant increase (**5.2** ± **3.7** to **8.2** ± **6.9**, (p = 0.18)), and CG2 experienced a non-significant decrease (**7.0** ± **8.4** to **5.0** ± **2.9**, (p = 0.19)). Overall, EG showed minimal increase in simulator sickness in both tasks, suggesting the AMVR method did not significantly add discomfort. CG1's increase in Task 2 and CG2's adaptation suggest varying impacts of traditional methods. None of these changes were statistically significant, supporting **H3**.

Table 7. Simulator Sickness Questionnaire score.

Task	Condition	PREAvg. ± PREstd.dev.	POSTAvg. ± POSTstd.dev.	p
Task1	EG	4.5 ± 1.6	5.3 ± 1.8	0.2
	CG1	3.8 ± 1.1	3.8 ± 1.1	0.5
	CG2	7.8 ± 5.3	7.8 ± 5.3	0.5
Task2	EG	3.2 ± 0.4	3.2 ± 0.4	0.5
	CG1	5.2 ± 3.7	8.2 ± 6.9	0.18
	CG2	7.0 ± 8.4	5.0 ± 2.9	0.19

5 Conclusion

The present study sought to address the pivotal yet understudied issue of determining the optimal position for virtual tour guides in VR museums, with the aim of enhancing user experience through reduced occlusion and improved multi-user sensory consistency. The development and evaluation of the Asymmetrical Mutual Virtual Retargeting (AMVR) method addresse key challenges related to user comfort, efficiency, and consistency, offering a promising solution for enhancing the multi-user VR museum experience. The findings of this study provide a solid foundation for further research and development aimed at refining the AMVR method and expanding its application to other domains of virtual human-computer interaction.

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