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CaliView: Continuous Viewpoint Calibration Using Dynamic Rotation Gain Control

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Abstract—Head tracking allows users of Virtual Reality (VR) to freely rotate their heads 360 degrees while exploring virtual environments. When using VR in a limited space, the ability to physically rotate one’s head is limited to a specific range. To address this issue, previous studies have proposed methods to employ distinct rotation factors for real and imaginary rotations. However, its primary usage lies in redirected walking; thus, it is unsuitable for seated VR. In this paper, we propose CaliView, which consistently adjusts the user’s perspective to always face an optimal direction in VR, all while ensuring a comfortable posture. CaliView continuously controls the rotation gain to ensure that the disparity between the present body orientation and the optimal orientation is reduced to zero, encouraging the user to assume a forward-facing position with the target orientation. To assess the suggested approach, CaliView, we experimented to compare three conditions: CaliView, snap turning only (Snap-Turn), and hybrid of CaliView and snap turning (Hybrid). The research findings suggest that CaliView functions as a useful reorientation technique, enabling implicit reorientation without sacrificing the user experience. Additionally, this study showcases its compatibility with various other techniques, such as the traditional snap-turn, thus emphasizing its versatility.

Index Terms—Virtual Reality, rotation gains, interaction techniques.

I. INTRODUCTION

In recent years, the popularity of virtual reality (VR) has surged significantly, primarily attributed to several key factors. These factors encompass the widespread acceptance and adoption of the metaverse concept, the accessibility of affordable VR devices, the establishment of reliable VR gaming platforms, and the global lockdowns enforced due to the COVID-19 pandemic. Room-scale VR provides the utmost immersive experience when it comes to VR. By fully utilizing the tracking technology found in Head-Mounted Displays (HMDs) and controllers, room-scale VR can offer an immersive experience that closely resembles being physically present in the VR environment. Although the allure of room-scale VR lies in its capacity to enable users to freely navigate and immerse themselves in virtual environments, it is also imperative to address the challenges associated with body rotation and movement, which arise from physical exhaustion and limited space for movement.

Numerous attempts have been made in the past to surmount the spatial limitations of VR play areas. Redirected Walking (RDW) is an innovative approach aimed at preventing collisions with walls by discreetly altering the walking direction, ensuring that the user remains unaware of the adjustment[1], [2]. RDW implements gains that impact the correlation between the user’s actual and virtual movements to achieve

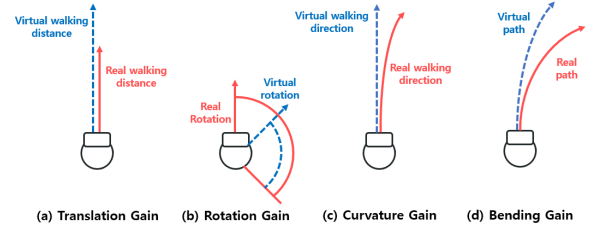


Fig. 1. The four distinct types of gains employed in RDW to manipulate perspective, namely: (a) translation gain, (b) rotation gain, (c) curvature gain, and (d) bending gain. The real and virtual transformations are represented by red and blue lines, respectively [12].

redirection and reorientation. The implicit adjustments are made by modifying the user’s walking path ((a), (c), (d) in Figure 1) or by rotating the VR environment as viewed through the user’s camera ((b) in Figure 1). The former types of modifications are typically implemented while the user is in motion, rendering them challenging to employ in circumstances with physically limited space, such as in a seated position. The latter modification type, often referred to as Rotation Gains or Amplified Head Rotation, remains significant even when spatial limitations are present. Consequently, it becomes the primary focus of this research.

Previous efforts have been made to utilize rotation gain as a means to address the challenge of head rotation within limited spaces [3], [4], [5]. Nevertheless, there have been limited endeavors to accomplish reorientation solely through rotation gains through methods apart from RDW. Given that RDW is predominantly designed to prevent collisions with physical boundaries in room-scale VR, its application becomes challenging in non-room-scale scenarios. Outside of RDW, the majority of instances where rotation gain was employed involved endeavors to enable a comprehensive view of 360 degrees despite the constraints of limited head rotation [3], [6], [7], [8]. Alternatively, it aimed to ascertain the user’s threshold for implementing rotation gain [9], [10], [11]. Hence, the primary objective of this research is to present a method of reorientation that can be applied not just to RDW but also to diverse scenarios, like seated VR, by employing rotational gain.

This research presents “CaliView”, a novel method for reorientation, and assesses its effectiveness through a between-subjects experiment. CaliView is a reorientation technique that continuously calibrates the user’s viewpoint to be constantly oriented toward the optimal direction in VR while maintaining

a comfortable posture. Instead of merely applying rotation gain to expand the range of angles, CaliView consistently adjusts the rotation gain in response to the user's body orientation, ensuring continuous compensation. CaliView assesses the required rotation gain by analyzing the difference between the current body orientation and the ideal orientation. Afterwards, it actively applies the rotation gain to guarantee that this difference is minimized to zero, motivating the user to adopt a forward facing position aligned with the desired orientation. The reorientation process is carried out seamlessly for the user without any noticeable impact and the need for direct involvement. Therefore, CaliView is anticipated to alleviate user exhaustion and enhance the user's immersive experience.

To assess CaliView, a between-subjects experiment was conducted to compare three conditions: CaliView, SnapTurn, and Hybrid. SnapTurn employs the conventional technique called snap turning, whereas Hybrid offers both CaliView and snap turning. The experiment was carried out by means of a trial that encompassed a total of 75 individuals, and involved basic VR navigation assignments. We gathered quantitative data, including the time taken for the experiments and the number of maneuvers performed, and qualitative data obtained through questionnaire responses to evaluate usability and motion sickness.

The main contributions of this study are as follows:

- We proposed CaliView, a novel method for reorientation that consistently calibrates the user's viewpoint to constantly align with the most optimal orientation in the realm of VR while simultaneously guaranteeing a comfortable stance.
- We describe the technical insights of CaliView, which is the process of altering the user's orientation solely by utilizing rotation gain, even in situations where there is no concept of collision with a wall.
- We implemented the CaliView to the VR system and evaluated the effectiveness and compatibility of CaliView with a between-subjects experiment comprising three distinct conditions: CaliView, SnapTurn as the conventional reorientation technique, and Hybrid that combines both techniques simultaneously.

II. RELATED WORKS

A. Reorientation Techniques in Redirected Walking

Many studies have been conducted on reorientation strategies to circumvent spatial constraints. One such instance is Redirected Walking (RDW), which modifies a user's walking direction surreptitiously. Razzaque et al. used stereo graphics and 3D spatial audio to implement the RDW technique, which resulted in users avoiding the walls of the lab. Based on their pilot study, it appears that RDW can subtly change the user's actual walking direction without causing additional simulator sickness [13], [14].

Most reorientation techniques involve subtly rotating the virtual world around the stationary user's center until they are properly oriented, ensuring that no physical obstacles are obstructing their path [15], [16], [17]. Steinicke et al.

mentioned the term "rotation gain" to refer to this rotation ratio and defined it in the following manner [9].

$$g_R := \frac{R_{\text{virtual}}}{R_{\text{real}}} \quad (1)$$

Real-world head rotations can be represented by a vector R_{real} composed of three angles: pitch, yaw, and roll. A rotation gain g_R is defined as the ratio of the specified component of a virtual world rotation R_{virtual} to the corresponding real-world rotation R_{real} . When a rotation gain g_R is applied to an actual head rotation with an angle θ , the resulting rotation of the virtual camera is $g_R \cdot \theta$ instead of θ . Another approach involves implementing reorientation as the user walks [18], [19], [20], [21]. However, in the context of stationary VR, the latter method appears to be less applicable.

Peck et al. proposed a system called Redirected Free Exploration with Distractors (RFED), which uses distractors to tell users when to stop and which direction to turn [22], [23]. Their approach is less effective in small spaces. For example, they reported that in a 3 x 3 m area, a distractor appeared after just 4–5 steps, leading to frequent redirections. Engel et al. examined an RDW technique redirecting users exclusively by considering rotation gain [24]. They implemented redirection by creating a system that dynamically calculates rotation gain to prevent users from crashing into walls. However, this system cannot be applied to stationary VR experiences as it presupposes physical movement in the actual environment.

RDW is designed to facilitate reorientation by actively utilizing gain, aligning with the objective of this research. However, a limitation of RDW is that a significant portion of the gain depends on the user's walking path, making it challenging to implement in scenarios where direct movement is not feasible. This naturally redirects the research attention toward rotational benefits that can be utilized even when the user is not engaged in walking.

B. Rotation Gains and Amplified Head Rotation

Amplified Head Rotation is a method that adjusts the virtual environment to align with the user's head rotation, resulting in an augmented rotation. This technique is commonly known as rotation gain, as the additional rotation factor is called rotation gain.

Several efforts have been made to utilize rotational gain as a strategy for surpassing the constraints imposed by limited head rotation angles. Langbehn et al. introduced two techniques that enable virtual 360-degree rotation in a physically limited space: Dynamic Rotation Gains and Scrolling [3]. Additionally, they put forward a method to rotate the environment imperceptibly to the user by leveraging the alteration in blink rate [6]. Nevertheless, there exists a hardware requirement that necessitates the capability to detect and identify the act of blinking. Kondo et al. suggested implementing dynamic feedback as a means to mitigate the artificiality associated with the application of rotation gain [25]. In their empirical investigations, they employed a gain of 1.1 for rotations equal to or below 30 degrees, 1.9 for rotations equal to or below 60 degrees, and 3.0 for rotations exceeding 60 degrees in relation to the HMD. Zhang et al. introduced a novel method for

enhancing head rotation in VR headsets, known as velocity-guided amplification [7]. This approach allows for adjusting the amplification factor based on the velocity of head rotation, ensuring that it remains within the range of comfort. Their method was purported to yield favorable outcomes without causing any discomfort to users. Hong et al. implemented a 360 video panning system, incorporating a constant and dynamic gain [4]. They implemented dynamic gain applying a range of gain values, varying from a minimum of 1.3 to a maximum of 1.6, based on the rotation speed of the HMD. Their results show that dynamic gain was more effective than constant gain.

Benda et al. compared manual camera rotation using a joystick to a manual reset technique using rotation gain and found that the joystick was preferred by users [26]. It could be suggested that the manual reset procedure could have potentially disrupted the user's natural experience. Yu et al. provided an account of their decision-making process in determining the application of rotational gain in their stationary VR experiment [5]. Three alternatives were taken into account: the continuous application of a fixed gain, the real-time rotation of the environment, and lastly, the dynamic application of the gain determined by the acceleration of the user's head rotation. The initial method was too noticeable to users, while the second one proved unsuitable for stationary scenarios, thus leading them to adopt a third approach characterized by dynamic amplification. Laviola et al. employed a method called Auto Rotation to surmount the challenges posed by the 270-degree CAVE environment [27]. Auto Rotation supports the user's rotation by making a slight rotation in the opposite direction as the user's rotation. Ragan et al. experimented to assess the impact of amplified head rotation on 3D search, spatial orientation, and cybersickness [8]. The study involved manipulating the degree of amplification and the type of display utilized (HMD or surround-screen CAVE) for the VR search task. The results indicate the possibility of utilizing amplified head rotation to observe a complete 360-degree virtual environment. However, significant issues were detected when employing high amplification in conjunction with a HMD.

Williams et al. introduced three techniques for "resetting" users when they encounter the physical boundaries of the HMD tracking system: Freeze-Backup, Freeze-Turn, and 2:1 Turn [28]. The act of resetting entails adjusting the users' position in the physical realm to relocate them away from the obstruction's trajectory, all the while ensuring their cognitive perception of the virtual environment remains intact. Specifically, 2:1 Turn has become widely adopted in the field of redirected walking [29], [30], [31], allowing for the reversal of the user's orientation by implementing a rotation gain of 2:1 at the specific moment when a reset is necessary. This demonstrates the feasibility of modifying the user's orientation solely by implementing rotation gains.

Several studies have explored the use of rotational gain, but their main focus has been on addressing the issue of limited rotation angles rather than using it as a method for active reorientation. Although 360-degree rotation is possible, applying Rotation Gains alone does not change the user's body

orientation. Hence, it is not possible to achieve reorientation by using a constant rotation gain, as the user's viewpoint will revert to its initial position when they rotate their body in the same direction. Therefore, the primary objective of this study is to focus on the dynamic adaptation of the rotation gain and its active utilization in directly modifying the user's orientation from the system.

C. Challenge with Previous Reorientation Techniques

This section consolidates the issues associated with current reorientation techniques and demonstrates the necessity for our suggested approach. Specifically, we're talking about snap turning, which are the most commonly used real-world VR reorientation technique, and RDW, which we discussed in Section II-A.

To begin with, each technique can be classified according to the taxonomy of redirection and reorientation techniques established by Suma et al [32]. Redirection and reorientation techniques are categorized based on three key elements: how they are applied in the environment (reposition or reorientation), the level of noticeability to the user (overt or subtle), and the implementation strategies employed (discrete or continuous). Suma et al. also carried out a subject experiment to assess each pattern, and it was found that the subtle and continuous reorientation techniques were highly favored. Subtle, continuous application is an effective method to enhance usability and maintain user immersion without their awareness.

Ironically, the most common reorientation technique currently in use is snap turning, an overt and discrete technique [33]. Due to the need for user interaction and the discrete nature of a screen switching technique, there is a clear reduction in the level of immersion experienced. Nevertheless, snap turning is experiencing extensive acceptance due to its ability to reorient effectively, surpassing the drawbacks. Additionally, it can significantly alleviate motion sickness, a crucial challenge of VR, further contributing to its popularity. However, it would be desirable if a subtle and continuous method could produce an equivalent outcome as a snap turning. There, Suma et al. defined rotational gain as a subtle and continuous technique, and research conducted on rotation gain indicates that moderate levels of gain do not exert a noteworthy influence on usability or the occurrence of motion sickness. Hence, if we can replace snap turning with a general-purpose reorientation technique that utilizes rotation gains, it is expected to contribute to an improved VR experience.

RDW is also an subtle and continuous redirection/reorientation approach, however, its efficacy relies on the user's unrestricted mobility within a specifically designated play zone. As various approaches exist to implementing RDW, not all RDW techniques will address this issue. However, the primary focus of RDW is to prevent collisions with the boundaries of the play area. Consequently, it is hard to utilize in Stationary VR, which inherently lacks this particular problem. Thus, the novelty of this work is to take the concept of RDW, which utilizes gains to reorient the user and makes it usable in stationary VR where physical collisions do not exist. This study aims to devise

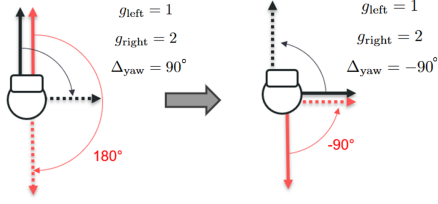


Fig. 2. Example of applying CaliView to turn the user's orientation 90 degrees to the right. The HMD orientation and its change are indicated by the black arrow, while the VR camera orientation and its change are represented by the red arrow. The direction before the change is represented by the solid line, while the direction after the change is depicted by the dashed line.

a methodology that establishes a Target Orientation as a basis for reorientation, enabling smooth and uninterrupted reorientation with increased effectiveness across a broader range of scenarios.

III. CALIVIEW

A. Technique to Calibrate Viewpoint

As the proposed technique, CaliView aims to consistently calibrate a user's viewpoint to ensure that the user's actual body orientation and the most ideal orientation for the user are aligned at the center. According to the taxonomy by Suma et al. [32], CaliView would be categorized as a Subtle Continuous Reorientation (SCR) technique.

This technique presupposes that the optimal orientation for the user (Target Orientation) has already been determined. Given the diverse objectives and types of VR applications, the approach to achieving the target orientation can differ. Consequently, the target orientation also serves as an input in CaliView. Regarding gain coefficients based on rotation velocity, a quadratic dependence was implemented to avoid sudden changes in gain, such as those seen in exponential models or fixed adjustments with linear dependencies. The details of specifications are as follows:

By default, the user's body orientation remains unchanged unless rotation gain is applied. For instance, if the user turns the HMD 60 degrees to the right with a rotation gain of 1.2 (20%), the camera rotation in VR will be 72 degrees (60 x 1.2). The difference between the actual rotation of the HMD in reality and the camera rotation in VR determines the alteration in body orientation, so the user's body orientation will be rotated 12 degrees to the right from the original direction. This is the reason that rotation gain can be used to achieve reorientation. CaliView determines the necessary rotation gain by evaluating the disparity between the present body orientation and the desired orientation. Subsequently, it actively implements the rotation gain to ensure that this disparity is reduced to zero, encouraging the user to assume a forward-facing position with the target orientation.

Figure 2 demonstrates an example of applying caliview to turn the user's orientation 90 degrees to the right. If the user applies $g_{\text{right}} = 2$ and $g_{\text{left}} = 1$ while turning 90 degrees to the right and 90 degrees to the left in real life, they will experience a 180-degree rotation to the right and a 90-degree

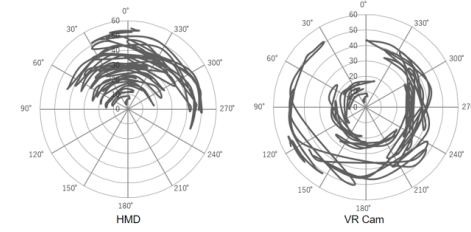


Fig. 3. Graph showing the change in orientation of the HMD and VR camera over time when CaliView is applied.

rotation to the left in VR. Consequently, the user will face the same direction as before in real life but rotated 90 degrees to the right in the VR environment.

Assuming that 120 degrees is the maximum angle that could be turned, the rotation gain applied was determined to have a maximum value of 1.83 and a minimum value of 0.69, which were established by referencing the values found in existing literature and conducting preliminary experimental tests. According to research findings indicating that the rotation gain becomes less perceptible as the HMD rotates at a faster rate, We implemented a dynamic rotation gain by utilizing the HMD's rotation speed and applying the subsequent equation.

$$g_{\text{right}} = \begin{cases} 1 + 0.83 \cdot \left(\frac{\Delta_{\text{yaw}}}{120}\right)^2, & \Delta_{\text{yaw}} > 0 \\ 1 - 0.31 \cdot \left(\frac{\Delta_{\text{yaw}}}{120}\right)^2, & \Delta_{\text{yaw}} < 0 \end{cases} \quad (2)$$

$$g_{\text{left}} = \begin{cases} 1 - 0.31 \cdot \left(\frac{\Delta_{\text{yaw}}}{120}\right)^2, & \Delta_{\text{yaw}} > 0 \\ 1 + 0.83 \cdot \left(\frac{\Delta_{\text{yaw}}}{120}\right)^2, & \Delta_{\text{yaw}} < 0 \end{cases} \quad (3)$$

Δ_{yaw} is the difference in camera orientation between the previous frame and the current frame.

Figure 3 depicts a visual representation illustrating the changing orientation of the HMD and VR camera over a period of time, specifically for one of the participants. The participant could observe his surroundings in VR even though the HMD predominantly maintained a field of view limited to 180 degrees.

B. Implementation

As for the Target Orientation, We postulated that navigation is present towards a waypoint specified by the user (see Figure 4), and the orientation that leads closest to that path is considered the desired target direction. The navigational route uses Unity's NavMesh to define the most efficient path, incorporating a 0.5-meter buffer for obstacles [34].

Before implementation, it was necessary to establish the upper and lower limits of the gain that would be utilized in the proposed approach. To accomplish this, a comprehensive review of all the research studies examining the threshold of gain perceptible to users was conducted. Steinicke et al. measured the extent of human reorientation that can occur without discrepancies between real and virtual movements, particularly in walking, translation, and rotation [9]. The results show that users can physically rotate by approximately 50% more or 20% less than the perceived virtual rotation, that distances can be increased or decreased by 14% and 26%, respectively,

and that users can rotate on a circular arc with a radius of more than 22 meters can be redirected while still thinking they are moving straight ahead. Fuglestad et al. also examined the threshold at which rotation, translation, and curvature gain could be detected using the HTC Vive [10]. According to their findings from the analysis of rotation gain, the calculated detection thresholds indicate that the rotation can be increased by 13% or reduced by 21%. Wang et al. examined the level to which individuals were able to discern the rotational amplification of the HMD when engaging in VR experiences while being seated, compared to standing condition [11]. Their findings suggest that individuals cannot differentiate between rotation gains of 0.89 and 1.28, a narrower range than the standing condition. Zhang et al. conducted an experiment in which participants rotated 360 degrees in the real world and indicated whether the rotation rate of the virtual world increased or decreased throughout the rotation [35]. Their study shows that gains can be changed quickly and in relatively large amounts without people being able to reliably tell whether the gain has increased or decreased. Their results show no difference between rotational gains that change gradually over a 360-degree rotation and gains that jump abruptly from one value to another. Sargunam et al. investigated the use of amplified head rotations so that physical rotation in a comfortable range can enable viewing of a virtual 360-degree area [36]. Additionally, they suggested a redirection technique called Guided Rotation to gradually realign the user's head position back to the neutral, straight-ahead position during virtual movement, preventing scenarios in which the user's neck is rotated in one direction uncomfortable position for a long period. Their evaluation found that the techniques worked as intended for the seated VR experience. Nevertheless, the findings illustrate the adverse consequences of employing semi-natural methods regarding spatial orientation, motion sickness, and overall user experience, in contrast to the conventional 360-rotation technique accompanied by one-to-one head tracking.

Initially, we adopted the most extensive array of thresholds observed in the studies, which was an upper limit of 1.8 and a lower limit of 0.8, to accommodate the inherent decline in gain as it adapts dynamically. However, the preliminary experiment demonstrated that the range of reorientation could be expanded. Therefore, we decided to extend the lower bound from 0.8 to 0.69 and the upper bound from 1.5 to 1.83 to achieve a more reliable reorientation. The increase in magnitude was quadratic as the rotation speed increased, assuming that the user's head could rotate within a range of -120 degrees to 120 degrees.

IV. EVALUATION

A. Experimental Setup

To examine the effectiveness of the proposed method, we conducted a between-subjects experiment comparing three experimental conditions: CaliView, snap turning only condition (SnapTurn), and hybrid with CaliView and snap turning condition (Hybrid). Snap turning is a widely adopted reorientation technique employed by prominent VR platforms such as SteamVR, Oculus, and similar systems. This technique



Fig. 4. Overview of VE used in this study. The green sphere is one of the tokens to collect. A visual cue for teleportation destinations is offered by the controller.

allows users to rotate their VR perspective to a specific degree through manual input from the VR controller. According to the taxonomy by Suma et al. [32], SnapTurn is an Overt Discrete Reorientation (ODR) technique. In this study, We employed the technique that utilizes the left and right sections of the Vive controller's trackpad as inputs. By pressing on either side, the virtual environment undergoes a swift rotation of 45 degrees in the direction of the press, accompanied by a brief dimming effect.

We also prepared hybrid conditions for comparison. When using CaliView alone, the user's reorientation is purely dependent on the user's HMD rotation, which can cause significant user fatigue. Since CaliView and snap turning do not conflict with each other in the application, and it would be natural to offer snap turning as well given real-world usage, We prepared a hybrid approach that enables the simultaneous utilization of both techniques. There are no differences in the implementation of each technique.

B. Task

This study set a simple task of collecting items because we aimed to clarify the basic advantages and disadvantages of the proposed method. Participants were required to gather a specific quantity of green spheres (referred to as "tokens") that manifested in a predetermined arrangement (Figure 5). The task did not impose any time constraints, and the measurement concluded once the designated number of tokens had been collected. Participants were required to gather a total of 25 tokens within a single session. Each token would sequentially emerge, and upon collecting one, the subsequent token would be unveiled. At the bottom is a green line corresponding to navigation, as shown in Figure 4, visualizing the shortest distance to the next token to aid the user's navigation and serve as CaliView's target orientation. Participants were also able to see the outline of tokens over the wall. Each participant had to complete three sessions, one for each method: CaliView, SnapTurn, and Hybrid. The order of each condition was determined randomly for each participant to prevent order effects. Furthermore, to ensure consistency across all patterns, the order in which tokens appeared in each session was carefully arranged to maintain identical travel distances, rotation angles, and directions.

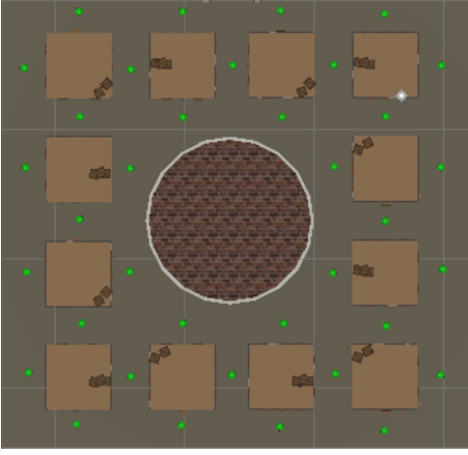


Fig. 5. A top-down view of VE used in this study. Tokens appear at the location of the green circle.

C. Apparatus

The system is driven by a PC with Intel Core i7-11800H @ 2.30GHz, 16GB RAM, and one NVIDIA GeForce RTX 3070 graphics card. The VR equipment used in the experiments was the HTC Vive Pro Eye HMD, with the included Vive controllers used for input. This HMD consists of two screens, each with a resolution of 1440×1600 per eye with a field-of-view of 110° diagonally, weighs 0.55 kg, and operates at an optical frame rate of 90Hz. The display device used was a HTC VIVE Pro Eye HMD, and the input devices used were the HTC Vive controllers. The camera movement was controlled by the user's head rotation using HMD.

The experiment VE was generated with Unity Engine (2021.3.14f1), a video game engine made by Unity Technologies. The VR setting comprised several square structures and sizable circular pillars strategically positioned to facilitate uncomplicated 90-degree rotations and smooth curvilinear motion (Figure 5). The method of locomotion in virtual environments (VE) was teleportation, utilizing the interface offered by Unity's SteamVR plugin as a default feature [37]. Teleportation was selected as the primary locomotion technique due to its widespread adoption in stationary VR [38], [39].

D. Participants

75 undergraduate and graduate students participated in this study. The mean age of the participants was 22.7 ($SD : 1.71$). 39 of them were male, and 36 were female. As for the experience using VR, most of the participants had little or no VR experience. There were an equal number of 25 participants for each of the three techniques, with a balanced distribution between male and female individuals. The participants were informed that they were allowed to cancel the experiment at any point if they started feeling too nauseous to continue, or even without any reason. However, no one had to stop the test due to severe motion sickness.

E. Measures

We collected data for objective and subjective evaluation. For the objective evaluation, we recorded the time taken to complete the task (Time), the number of snap turning performed (STCount), the number of teleports made (TPCount), the cumulative rotation angle of the HMD (HMDRot) and VR camera (VRRot).

For the subjective evaluation, five different types of questionnaires were employed as follows: the System Usability Scale(SUS) for usability [40], the Simulator Sickness Questionnaire (SSQ)[41] to assessing motion sickness, the NASA-TLX (Task Load Index) for mental workload[42], the IPQ (Igroup Presence Questionnaire) to assess the sense of presence in a virtual environment¹, and Discomfort score. The discomfort score is the original questionnaire on a 10 scale, where higher scores denoted greater discomfort.

F. Analysis

The analysis is IBM SPSS Statistics 27.0.1.0. We conducted one-way ANOVA with repeated measures for the Time and VRRot. We also conducted a t-test for STCount between SnapTurn and Hybrid since the snap turning operation was not provided in CaliView. For the remaining quantitative data (TPCount, HMDRot, SUS) and qualitative data, the relevant normality assumptions were not satisfied. Therefore, we used the Kruskal-Wallis test. P values less than 0.05 were considered significant at all statistical tests.

G. Procedures

Each participant conducted three experimental sessions using only one assigned technique. To compare data after participants had adapted to the experiment, the data from the final session was examined exclusively. The specificities of the experimental protocol are outlined as follows. Firstly, the experimental procedure was thoroughly explained to the participants, and their consent forms were obtained. Subsequently, the participants completed the SSQ questionnaire to establish a baseline for symptoms before commencing the task. Upon completion of the questionnaire, participants were instructed to put on the HMD, and we provided them with an explanation of how to utilize the locomotion interface using the Vive controller. Note that during the experiment, the participants for the CaliView and Hybrid conditions were not provided with any details regarding the precise workings of CaliView. They were informed that a form of assistance for manipulating perspectives was being utilized. They were then guided to freely navigate the virtual environment until they felt at ease, treating it as a practice trial. Next, in the main session, participants collected 25 green tokens for each condition. Upon completing the one session, the participant proceeded to detach the HMD and provide responses to the questionnaires. Subsequently, 10 minutes of rest was allocated to alleviate any fatigue or motion sickness experienced before transitioning to the next session. They did a series of processes three times.

¹<http://www.igroup.org/pq/ipq/index.php>

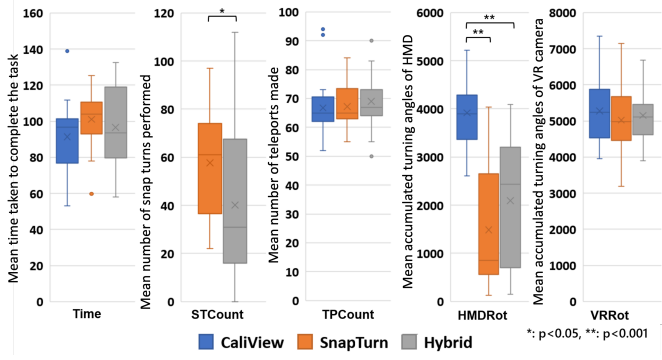


Fig. 6. Box-and-Whisker plots showing performance data from the third session. The information depicted in each graph, in sequential order from left to right, includes Time, STCount, TPCount, HMDRot, and VRRot.

TABLE I
MEAN SCORES OF IPQ.

	CaliView		SnapTurn		Hybrid	
	Mean	SD	Mean	SD	Mean	SD
General Presence	3.44	1.55	3.60	1.39	3.36	1.20
Spatial Presence	3.12	1.02	3.11	0.99	3.06	0.93
Involvement	4.02	1.18	3.64	1.12	4.21	1.14
Reality	1.72	0.76	1.73	0.67	1.67	0.57

H. Results

I. Objective Evaluation

Figure 6 shows the mean results of the Time, STCount, TPCount, HMDRot and VRRot. Regarding STCount, the t-test results showed a significant difference between SnapTurn and Hybrid (Hybrid < SnapTurn, $p = .032$). The results of the Kruskal-Wallis test showed significant differences in HMDRot ($H=36.431$, $df=2$, $p<.001$). For HMDRot, multiple comparisons with Bonferroni's method showed a significant difference between CaliView and the others (SnapTurn, Hybrid < CaliView, $p < .001$).

J. Subjective Evaluation

The mean results of the SUS scores were as follows: CaliView was 75.80 ($SD: 10.60$), SnapTurn was 79.40 ($SD: 8.01$), and Hybrid was 80.20 ($SD: 8.03$). The result revealed no significant difference between each method. All conditions achieved over 68, the SUS average score.

The mean results of the SSQ scores from the third experiment session are shown in Figure 7. We calculated the difference between the score at the beginning of the whole experiment and after each experiment. Then, we used this value for the analysis. Only the total score (TS) from the third experiment session was used for analysis. The result of the Kruskal-Wallis test showed a significant difference ($H=6.186$, $df=2$, $p=.045$). Multiple comparisons with Bonferroni's method showed a significant difference between CaliView and SnapTurn (SnapTurn < CaliView, $p = .039$).

The mean results of the NASA-TLX scores were as follows: CaliView was 52.80 ($SD: 22.62$), SnapTurn was 45.81 ($SD:$

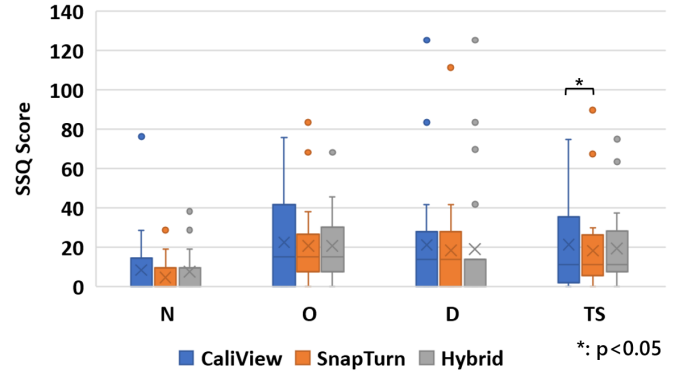


Fig. 7. Box-and-Whisker plots showing the SSQ scores from the final session. The weighted SSQ sub-scores for Nausea (N), Oculomotor (O), and Disorientation (D), and the Total Severity (TS) were calculated.

TABLE II
MEAN SCORES OF CONCEIVED DISCOMFORT.

	CaliView		SnapTurn		Hybrid	
	Mean	SD	Mean	SD	Mean	SD
Discomfort Score	4.28	2.89	3.08	1.83	3.80	2.53

17.78), and Hybrid was 42.63 ($SD: 18.31$). The result revealed no significant difference between each method.

The mean results of the IPQ scores are shown in Table I. The result of the Kruskal-Wallis test revealed no significant difference between each method.

The mean results of the discomfort scores were as follows: CaliView was 4.28 ($SD: 2.89$), SnapTurn was 3.08 ($SD: 1.83$), and Hybrid was 3.80 ($SD: 2.53$). The result of the Kruskal-Wallis test revealed no significant difference between each method.

V. DISCUSSION

For quantitative evaluation, we measured the time taken to complete the task (Time), the number of snap turning performed (STCount), the number of teleports made (TPCount), and the cumulative rotation angle of the HMD (HMDRot) and VR camera (VRRot). No differences were observed among the techniques in relation to the frequency of teleportations and the rotation of the VR camera. Hybrid allowed users to use significantly less snap turning compared to the SnapTurn condition. This means that CaliView's implementation leads to a notable decrease in the requirement for snap turning in Hybrid, thereby minimizing the instances where users have to manually handle them. CaliView necessitated a considerably greater amount of HMD rotation than Hybrid and SnapTurn. This can be inferred as a contributing factor to increased fatigue, as indicated by CaliView's SSQ score, which was equally elevated compared to SnapTurn. However, we successfully aided in the reorientation process without any substantial disparities in terms of time, NASA-TLX, SUS scores, and each IPQ item. It is worth mentioning that there was no significant difference observed in NASA-TLX, also known as task fatigue, between any of the techniques. There are several possible causes for these results. First, participants were not

cognizant of the fact that CaliView implements rotation gain while rotating the HMD, so they might have mistakenly associated the fatigue they encountered with their engagement in VR tasks. It indicates that the consistent adjustment function of CaliView was effective for the task. However, in cases such as a maze task, where the user does not know the direction they should head, the consistently adjusting function may have a negative impact. Future research should include additional verification considering such scenarios.

Alternatively, there may be some mental fatigue involved in maneuvering the snap turning, which may have compensated for the physical fatigue experienced in CaliView in the NASA-TLX score. Although there exists a notable difference in SSQ scores between CaliView and SnapTurn, no significant difference is observed with Hybrid. Hence, when combined with other methodologies like SnapTurn, CaliView can aid users in maintaining their orientation without experiencing a significant decrease in usability or fatigue.

Based on the comprehensive outcomes, CaliView holds potential as a reorientation technique in VR applications that provide target orientation (e.g., racing games, parkour games, etc.). In particular, the fact that it does not require direct user interaction is expected to enable various applications. Due to its manipulation-free nature, this technology can be utilized with or without any VR controller. Furthermore, although CaliView operates under the assumption that one cannot physically rotate their body, such as when seated, it should be noted that this does not preclude its applicability in room-scale VR environments. CaliView can be a valuable tool to facilitate reorientation in room-scale VR, similar to the concept of redirected walking.

VI. LIMITATION

The findings indicate that CaliView serves as a valuable technique for reorientation. Nevertheless, certain constraints should be acknowledged in our study.

Besides setting the target orientation to CaliView, CaliView necessitates the system to provide an ideal target orientation for users, which may not always be feasible. When the user is not provided with directions or lacks knowledge about their destination, such as when they come across a junction in a labyrinth, the application of CaliView becomes impractical as it is impossible to ascertain the target orientation. While CaliView serves as a valuable method for reorientation, we opine that its optimal utilization should be in conjunction with other techniques, like Hybrid.

Concerns have been raised regarding the experimental design, specifically regarding the simplicity of the environment and tasks in assessing generality. As mentioned before, for example, if a greater frequency or a larger magnitude of rotation were necessary, such as maze tasks, where the user does not know where they should head, the outcomes might have varied. It should investigate more complex scenarios in future work.

Several constraints were identified in the execution of methods. The rotation gain's upper and lower boundaries were uniform across all participants, which raises the possibility

that certain users might not have received the appropriate values. A personalized threshold could have been established for each user through a calibration process, potentially leading to improved usability outcomes. Improving usability may help reduce motion sickness issues caused by HMD rotation. Additionally, future work should also focus on verifying fatigue accumulation from prolonged usage.

Furthermore, it is worth noting that the participants in this study were exclusively undergraduate or graduate students, and the majority of these participants had limited exposure to VR technology. This homogeneity in the sample population could potentially have influenced the outcomes of the experiment.

VII. CONCLUSION

This study presented a novel approach that utilizes dynamic rotation gains to enable rotation within a virtual environment when faced with the constraint of a limited physical turning angle. The technique, CaliView, exhibited comparable performance to SnapTurn in terms of performance, usability, and workload in exchange for an increase in motion sickness due to more head rotation. However, when combined with snap turning, Hybrid enabled to minimize user interaction without sacrificing other factors. Future research questions include how to obtain target orientation, or how to apply CaliView in the absence of target orientation, and demonstrating its usefulness under different conditions.

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