[DC] Gaze-Based Viewport Control in VR

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Abstract

Head-Mounted Displays (HMD) allow users to explore Virtual Reality (VR) environments via extensive head and body movements. In this work, we introduce novel gaze-based techniques for viewport control. These allow users to explore VR environments without moving their head, body, or hands, nor need to use any external controllers other than an eye-tracker. The techniques have been evaluated and compared against traditional alternatives in an abstract study and a video-watching study - demonstrating comparable performance, task load, cybersickness, and user preference. Future research seeks to improve its applicability in a variety of real-world settings, necessitating investigations into how it affects hand-eye coordination and its impact on interactions and interface design. Combined, these should address the need for more accessible and ergonomic exploration methods in VR, particularly for users with limited mobility or those in confined spaces.

Index Terms: Virtual Reality, Camera Control, Eye-Tracking, Interaction Techniques, User Studies, Human-Computer Interaction.

1 Introduction and Related Work

In traditional VR experiences, an absolute mapping between the HMD and the virtual viewport allows users to explore their surroundings by turning their heads or bodies. Although immersive, this approach presents challenges for users with limited mobility (e.g. injury, disability), environmental constraints (e.g. limited space, social perception in public settings), or comfort needs (e.g. wanting to be seated or lying down) [6]. Extensive head movement or physical interaction with the virtual environment has also been shown to worsen ergonomics[7] and cybersickness[2]. Several categories of alternate viewport control techniques that reduce the cost of looking around exist in the literature.

Controller-based techniques use buttons or joysticks on handheld controllers, allowing users to manually control the viewport. Notable examples include *Controller Snap* - which snappily rotates the viewport on button/joystick trigger; and *Controller Drag* - which allows the user to "drag" the world around them whilst a button is held down.

Head Amplification techniques such as *Head Gain*, amplify head movements, enabling users to explore virtual spaces beyond their physical limitations.

Posture-Based techniques substitutes head movement with movement of other parts of the body. Often, these techniques are a component of locomotion techniques in literature, and would utilize body leaning, shoulder-steering, or arm swiping for viewport control.

Automatic Viewport Control techniques automatically adjust the user's viewport or body and is primarily used in storytelling settings. These could virtually move the viewport along fixed paths or have the user be on an external device that reorients them in reality.

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Field-of-View (FOV) Expansion techniques artificially broaden the user's FOV by overlapping views or by introducing portals or mirrors.

A user's gaze and viewport direction are both natural indicators of interest - using gaze for viewport control could be synergistic. However, many of our eye-movements are instinctive, fast, and hard to intentionally control. Further complicated by the imprecise nature of current eye-tracking, gaze as an alternate modality for viewport control has remained largely unexplored.

As such, we investigate the affordances of gaze-based viewport control in VR, focusing on the development, evaluation, and application of novel techniques. It addresses several research problems:

- RQ1 How can gaze behaviour be leveraged for viewport control (yaw + pitch rotation)?
- RQ2 What are the affordances and key parameters of the gaze techniques in RQ1 for different real-world applications?
- RQ3 How does gaze-based viewport control affect hand-eye coordination and other common VR interactions?
- RQ4 Following RQ3, How would it affect the design of VR experiences and interfaces?

We believe that these contributions would improve the accessibility and ergonomics of VR while providing a foundation for VR controls that are decoupled from our physical posture, allowing VR to be used comfortably in a wider variety of situations.

2 Research Progress

For RQ1, we developed three viewport control techniques that leverage gaze based on different types of eye movements [5].

- *Dwell Snap* is based on prolonged fixation, similar to holding a button down to trigger viewport rotation in discrete steps.
- *Gaze Gain* is based on saccades and uses a transfer function with the gaze angle as input for the amplified rotation of the viewport.
- *Gaze Pursuit* is based on pursuit and rotates the view toward the direction of the user gaze, allowing them to follow a target until it is centrally aligned in the field of view (FOV).

These techniques were evaluated in a yaw-only scenario via a modified abstract peephole study [1]. Participants (N=20) had to align the center of the viewport by yaw-rotating it toward known and unknown targets at different levels of precision. Compared to our baselines of *Controller Snap* and *Head Gain*, we found that all three gaze-based techniques proved effective for viewport control, as they were comparable to baseline techniques in terms of error rate, alignment time, task load, simulator sickness (SSQ), and amount of head movement[5]. Post-hoc analysis also revealed nuanced behavioral patterns exhibited by users that we categorize as head movers and non-head movers, representing a user's inclination to move their head over using any provided technique [3].

Despite the positive results of our techniques, the study abstract setting had reviewers raise questions about its applicability and integration in real-world applications. Therefore, we decided that evaluating the techniques for 360° video watching would be appropriate, as they are commonly a user's first experience of VR. We surveyed existing popular consumer-available 360° video players (n=28) and discovered that all players supported 1:1 head mapping, half supported controller-based viewport control, and none supported any other form of viewport control by default [4]. The two most popular alternate viewport techniques found in our survey, *Controller Drag* (n=7) and *Controller Snap* (n=4), were then used as baselines for a 360° video-watching study. In our study, participants (n=20) had to first watch a short 360° video (4m 40s) five times - once with each technique for comparison purposes, then watch a longer 360° 3D video (11m 30s) with their preferred gaze-based technique to investigate viewing behavior and the viability of gaze-based viewport control for 3D videos.

The study found that gaze-based viewport control techniques were competitive to the baselines in task load, cybersickness, ease-of-use, controllability and amount of head movement, corroborating with our previous abstract study. Participants generally preferred these techniques, though preferences varied individually. Sustained engagement was observed, with consistent use throughout longer videos, and user experience remained stable over time. However, prolonged exposure highlighted limitations, and participants suggested adjustments to parameters such as rotation speed, dwell time, and sensitivity. This points to the need for further refinements and the potential benefit of offering user-adjustable parameters.

Although these two studies do not fully answer RQ1, they contribute to understanding gaze-based viewport control in VR and demonstrate its potential as a viable and effective alternative to traditional techniques.

3 Future Research and Discussion

In our studies so far, gaze only controlled the viewport yaw-rotation without affecting its pitch, leaving RQ1 partially satisfied. Furthermore, our study participants were all comfortably seated with little variety in posture, and the applicability of gaze-based viewport control in other real-world scenarios such as virtual tours, data visualization, and gaming remains unexplored.

Preliminary experiments indicates that our techniques could be generalized to work with pitch-only or multi-dimensional rotation regardless of posture. However, viability outside the lab remains uncertain and is our next step forward.

Building upon the results of our two studies, new questions also emerge. For example, could our analysis of head and non-head movers from the first study have been applied to personalize viewport control techniques in the second study, reducing participants' desire for parameter adjustments after viewing the longer video?

For RQ2, we intend to extract the affordances and key parameters from participants' gaze behavior during video watching and their comments about parameter adjustments. This will initially aid in fine-tuning our existing techniques, but our broader aspiration is to create an extensive design framework for gaze-based viewport control. However, this endeavour will likely require a deeper exploration of its influence on hand-eye coordination (RQ3) and its integration into VR experience and interface design (RQ4), including non-video-watching contexts to ensure generalizability.

For RQ3 and RQ4, designing an experiment to answer them is complex. Gaze-based viewport control likely influences other common VR interactions, which in turn affects our study design. For example, a user with their hands unmoving outstretched in front of them could still rotate the viewport with their gaze. Should the hands follow along to remain virtually in-front of them? Or stay unmoving since physically, the hands did not move? Perhaps the hands should lag behind, as the eyes tend to move ahead of the hands during eye-hand coordination tasks?

Insights into this and the following questions are the main agendas on which we seek advice.

- How should we study impacts on hand-eye coordination, especially considering interactions that are otherwise impossible in reality are possible?
- Are there interaction techniques (e.g. from redirected walking, haptic retargeting) that could work well with gaze-based viewport control?
- How can we do a longitudinal ecological validity study of the techniques considering the multitude of factors (e.g posture, user adaptation, application/hardware differences)

4 Conclusion

This research introduces three new gaze-based viewport controls that allow users to explore VR environments without moving their heads, bodies, or hands. Users also do not need to use any external controllers other than an eye-tracker. Evaluated in both abstract tasks and 360° video-watching scenarios, these techniques demonstrated promising results compared to existing methods in academia and industry. Current work is focused on fine-tuning yaw+pitch control and ensuring usability across a range of user postures. Future efforts will investigate the techniques' impact on hand-eye coordination and their implications for VR interface design, paving the way for broader applications. With continued development, these gaze-based controls have the potential to redefine how, where, and when users use VR, exposing VR to more novel use-cases.

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