The Gaze Stability Challenges Associated with AR User Interfaces During Locomotion

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1 Background and Experience

I am a first year PhD student working on what I believe to be a key challenge facing AR on-the-move – the stability of gaze. When we walk, AR UIs placed using existing techniques reproduce body movements in a way which the human visual system cannot effectively compensate for. The result of this is excessive eye movement relative to the UI, threatening both gaze interaction and visual perception. With my work on this topic, I aim to improve our understanding of how different patterns of UI movement contribute to gaze instability; develop new UI placement approaches which minimise the issue; and explore the implications of this for different tasks. In this position paper, I will explain why we encounter gaze instability during locomotion, and why I believe this constitutes a major challenge facing AR on-the-move.

2 Gaze Stabilisation On-the-Move

If users are to successfully accomplish their tasks during locomotion, it is often necessary for the required AR user interfaces to move along with them. There must, therefore, be some mechanism by which the user's motion through the environment is translated into corresponding motion of the UI. This mechanism might be as simple as fixing the UI relative to the user's body, or it may be more complex, but it is ultimately a decision that the UI designer must make. The consequences of this decision can include significant impacts on gaze stability.

The ability of a user to hold their gaze stable on a target is relevant for many tasks. It is important whenever we use gaze as an interaction technique, but it also impacts visual perception – if a target moves too fast relative to the eye, the image on the retina becomes blurred and visual acuity drops [6], causing difficulty reading [4], for example. When walking and reading in AR during locomotion, performance is better when the UI is stable in the world compared to when it moves with the head [4, 7]. This forms part of a more general trend where the more a UI moves in a plane perpendicular to the direction of motion, the harder it becomes to fixate stably upon it [13]. The explanation for this trend lies in the motion of the body, the ways it is transferred to the UI, and the corresponding response of the human visual system.

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During locomotion, the motion of the human upper body is not smooth progression through the world, nor is it beset by noise, but rather it is characterised predominantly by sinusoidal oscillations [9]. As we walk, our head moves through a cycle of vertical translation and pitch rotation every step, and through a similar cycle of horizontal translation and yaw rotation every two steps [15]. The torso moves with similar patterns but greater magnitude [9].

The consequence of this is that when a UI is anchored to the human body, it necessarily reproduces its oscillating motion. Not all approaches to on-the-go UI placement involve rigidly fixing it to the body — sometimes vertical translations are ignored [10, 16], rotation is damped or eliminated [10, 3, 14], or the forward direction is provided by velocity [11] — but none of these approaches entirely avoid reproducing the oscillations. The idea of placing a UI in a way that does not reproduce body oscillations at all, moving only in the direction of progression, has been proposed [13] but presents as-yet-unaddressed implementation challenges.

Of course, when we walk and look at targets in the world, our visual acuity is not significantly impaired, at least, other than for targets which are especially close or when we are moving especially quickly [5]. Why, then, do we sometimes observe gaze stability issues in AR? The answer lies in the nature of the human visual system's gaze stabilisation mechanisms. These mechanisms have two main components — the vestibulo-ocular reflex (VOR), which moves the eyes to oppose motion of the head, and a visual component, which moves the eyes in pursuit of the target [2]. In typical circumstances, these mechanisms act to complement each other, with the VOR predominating during locomotion [8]. However, when we consider a target which follows some of the motion of the head, as most AR UIs do, then this vestibular part of the response is unnecessary and optimal gaze stability requires that it be suppressed. Visual gaze stabilisation mechanisms are capable of VOR suppression in some circumstances but experiments exploring the impact of oscillation on the human visual system tell us that, as the frequency is raised through the 1 Hz to 2 Hz range, the visual suppression of the VOR breaks down [1]. In physical locomotion, where frequencies of stepping of around 2 Hz are very common [12], this presents a clear threat to gaze stability.

While there is still much that we do not know about this issue, it is evident that reproducing the locomotion-induced oscillation of the body is not always amenable to the natural gaze stabilisation mechanisms of humans. As a consequence, across the landscape of existing UI placements on-the-move, there is always the possibility that users will find their visual acuity or gaze pointing to be impaired. I believe this is a key challenge for AR on-the-move, with broad relevance to different tasks, and one that we must seek to address through the placement and design of our UIs.

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