[DC] Understanding and Leveraging Head Movement as Input for Interaction

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ABSTRACT

Head movement is an intuitive and fundamental input modality for interactions. This PhD investigates head movement as an input modality for improving interaction efficiency and user experience. It encompasses three core components: 1) a systematic literature review analysing existing head interaction techniques, 2) the development and evaluation of head interaction techniques for head-mounted displays (HMDs), and 3) the generalisation of design principles derived from HMD-based research to other interfaces. The design of interaction techniques integrates fundamental knowledge of head movement kinematics, the natural coordination of the head with the eyes and hands, and control-display mappings. This research contributes to understanding head movement as an input modality and novel interaction techniques that harness its potential to enhance user interfaces across a range of devices.

Index Terms: Human-Computer Interaction, Virtual Reality, Head-Mounted Display, Head Movement, Eye-tracking, Control-Display Gain.

1 INTRODUCTION

Head input is the most readily available modality and is an attractive interaction method. As users have a fine-grained and large range of control over head movement, head movement offers a precise [2], stable [7], and wide range of rotational input [3]. Head input can be used as a hands-free method when hands are busy and for users with physical challenges. It is also promising as an extra modality for complementing hand interactions, especially for tasks requiring progressive refinement and separation of degrees of freedom (DoF).

However, head-based interaction faces several challenges with Head-mounted displays (HMDs). Using head movement as input requires constant implicit control with neck muscles. This can be fatiguing over time, especially with large areas in 3D [5]. The second challenge lies in the conflict between visual-driven head movement and gestural head movement [2]. As head movement is involved in the visual process, head rotation triggered to support the visual search of targets [6] can be accidentally recognized as gestural input in interaction [2], causing frustration. A third challenge is that head movement is affected by the limited eye-in-head position, that eyes would not normally offset more than 30° from the head vector [6]. This means performing large-amplitude head rotations for control while keeping gaze focused on the target can cause eye fatigue.

Against these challenges, this PhD investigates interaction techniques based on head movement input to improve interaction efficiency and user experience. This involves exploring, prototyping, fine-tuning, and evaluating interaction techniques against baselines with abstract and application tasks. The design process of the techniques integrates fundamental knowledge of head movement kinematics, control-display transfer functions design, and coordination with other modalities such as eye and hand. The projects within the PhD start with HMDs and virtual reality (VR) as a controlled experimental platform and will, in the end, extend to other interfaces. To achieve this, we formulate the following key research questions:

- **RQ1:** How was head movement used as input in interaction?
- **RQ2:** How to use the head as input for interfaces in HMDs?
- **RQ3:** How can insights be generalized to other interfaces?

2 RESEARCH PROGRESS

We plan our research and structure the PhD into three parts following the three key research questions: 1) systematic literature review of head interaction techniques, 2) building head interaction techniques with HMDs, and 3) generalising design principles to other interfaces.

2.1 Systematic Literature Review

The systematic review is now in progress. It is motivated by a lack of synthesis of decades of work on head interaction techniques, thus answering **RQ1**. We want to collect insights from the previous work and identify areas for future research in the field. This also involves collecting the head movement basics, head movement coordination with other modalities, and CD mapping functions to inform the interaction design for the rest of the PhD.

The review is conducted following the PRISMA method [1]. We have included 155 papers published before 2023 and proposed interaction method(s) with head input beyond 1:1 camera control into the dataset. We are currently collecting information from the papers and plan to also include papers published in 2024.

2.2 Head Interaction Techniques with HMDs

Developing head interaction techniques with HMDs in VR is the majority of the PhD. This contains three projects that explore **RQ2** via prototyping and evaluating head interaction techniques to improve the efficiency for pointing, positioning, and rotate-scale-translate (RST) tasks. We investigate the head as a multi-modal input that elicits and coordinates with the movement of eyes and hands.

2.2.1 Work Completed

We completed HeadShift [8] as a head-pointing technique as the first project. The work focused on integrating eye-head coordination in head pointing with head input as the primary and unimodal. This project provided an overview of the structure of this section of the PhD, which integrated eye-head coordination, aimed movement kinematics model, and CD mapping in the design, with evaluations performed on both abstract and application-based tasks. The technique was designed not limited to facilitating head pointing with HMDs but is also generally applicable across devices and contexts.

HeadShift implements a dynamic CD gain inspired by natural eye-head coordination to enhance head pointing (Figure 1). It addresses the limitations of traditional 1:1 head pointing, which requires excessive head movement and lacks precision. During target pointing, the gain function in HeadShift fastly offsets the cursor

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following natural eye-head coordination and transitions to slower, fine-grained adjustments for precise cursor control, following the aimed movement kinematics model [4].

Results from Fitts' Law and three application studies with two types of HMDs indicated that HeadShift enhances accuracy and ergonomics against the baseline 1:1 mapping. It relies solely on head movement properties and is adaptable to other types of devices. Building on the specifics of HeadShift, we propose a design principle for head pointing that leverages CD gain functions integrated with the natural coordination between eye and head movements.

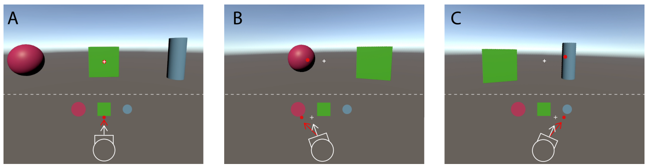

Figure 1: HeadShift reduces the amount of head movement required for moving the cursor (red dot) and makes targets selectable within a comfortable gaze range around the head vector (white cross).

2.2.2 Work-in-Progress

The second project is now in progress, and we aim to use eye and head for concurrent bimodal input. Specifically, we built a technique to specify a position in 3D space. We used eye gaze for raycast and head pitch to specify depth values along the gaze ray with CD gain (Figure 2). Within the abstract task, we found that the technique could not be performed with high gaze accuracy, as performing head rotation during eye fixation would decrease eye-tracking accuracy and shift the gaze point around. We are currently designing experiments on application tasks for hands-free scenarios and as a complementary method for supporting the tasks in which hands have already been involved.

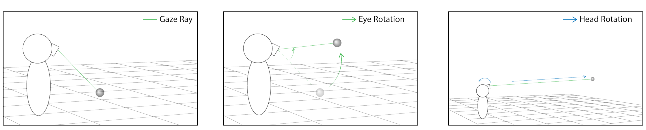

Figure 2: Specifying a 3D position in mid-air with eye gaze (green) and head movement (blue), with gaze defining direction and vertical (pitch) head rotation controlling depth with control-display (CD) gain.

The third project (**Topic1**) will be a trimodal interaction integrating head, eyes, and hands input for RST tasks. The major focus would be exploring the best role of head input when integrated with other modalities and how head input can best fit in the multimodal technique design. This will involve building and exploring within a design space and evaluating techniques that use head input for different roles on RST tasks.

2.3 Head Interaction Techniques beyond HMDs

HMDs remain at the forefront of displays in professional contexts, such as training and experimental settings, but are still not widely adopted for everyday use. We plan this final project of this PhD (**Topic2**) to leverage the insights gained from the research with HMDs to enhance head-input interactions on devices commonly used in everyday contexts, such as desktops and IoT systems, for **RQ3**. This involves extending and validating the design principles from subsection 2.2 in these new contexts and serving as an overall ecological validation. This last part will focus on creating practical solutions that users can easily and seamlessly integrate into their existing devices to improve efficiency and user experience.

3 Feedback and Advice

We seek advice and ideas on the third project in subsection 2.2 (**Topic1**) and subsection 2.3 (**Topic2**). Specific feedback topics are formatted below:

- **Topic1**: Study design recommendations and examples on exploring the role of head input in multimodal RST tasks.
- **Topic2**: Promising types of devices, tasks, applications scenarios, and problems that can be potentially solved by integrating head as input beyond HMDs.

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