Imperceptible Manipulation of Lateral Camera Motion for Improved Virtual Reality Applications

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Abstract

We measure detection thresholds for lateral translation gains of virtual camera motion in response to the corresponding head motion under natural viewing. We propose three applications for our method, addressing three key problems in virtual reality, and validate their improvement when our manipulation technique is applied.

Introduction

Users' physical movement in virtual reality (VR) systems increases immersion and can evoke a sense of spatial presence [1], while contributing to a more comfortable experience due to visual-vestibular consistency [2]. Interestingly, large mismatches between such physical movement and its virtual counterpart might remain unnoticed [3]. This has been leveraged in the context of forward locomotion, enabling the exploration of virtual worlds larger than the available physical space [4].

At the same time, many VR applications require that the user be seated or standing, with only head and upper body motion available. In the absence of forward locomotion, lateral head translation becomes particularly relevant: It is a quite natural motion, and it also facilitates scene understanding by triggering motion parallax [5], and increases perceived realism.

Given all this, in this work, we investigate manipulations of the virtual camera motion in the range of moderate head translation (i.e., the range of natural head movements spawned while exploring content without explicit locomotion). Our experiments allow us to obtain detection thresholds for translation gains (i.e., the ratio between the virtual and the real movement). These detection thresholds indicate the range of manipulations that can be carried out without the user noticing them, both for compression and expansion of the lateral head motion in VR, in response to the corresponding head motion in the real world. Additionally, we have discovered a novel dependency of these thresholds with scene depth layout.

In addition, we demonstrate the potential of our measured detection thresholds in three proof-of-concept applications addressing key open problems in VR for which definite solutions do not exist (see Fig. 1, right): (i) improving 6-DoF (six degrees of freedom) viewing for captured content, (ii) overcoming physical space constraints, and (iii) reducing simulator sickness. Our validation studies show that our measured detection thresholds can offer an improvement for all three of them. We offer here a brief summary of the main contributions, and refer the interested reader to the extended version [6].

Psychophysical Experiments

In order to measure the detection thresholds, we conducted a perceptual experiment based on a two-alternative forced-choice (2AFC) task with a method of constant stimuli. In each trial, subjects were presented with one stimulus with a certain translation gain applied to the camera, and a particular scene depth layout, and they had to choose whether the virtual movement they observed was smaller or larger than their physical movement. Since users are forced to choose one of these two options, unnoticed translation gains will be answered randomly, and therefore they will be correctly answered in 50% of the cases on average, which is termed the point of subjective equality (PSE). Varying the translation gain g_T and measuring the probability of answering larger (or smaller) results in a number of points, to which a psychometric curve will be fitted. This curve models detection performance (see Fig.1, left).

Detection thresholds (DTs) are defined as the gain values at which participants can just detect a discrepancy between the two conditions. We follow convention and set this threshold at 75% (halfway

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between the PSE and 100%) for correctly answering that the virtual movement was larger (expansion detection threshold), and at 25% (halfway between the PSE and 0%) for correctly answering that the virtual movement was smaller (compression detection threshold). The interval between those two thresholds determines the range of possible translation gains that can be unnoticeably applied.

We have found a statistically significant difference for both the PSE and DTs for different scene depth layouts. This indicates that participants' perception of a natural movement (1:1 mapping of real to virtual movement) varies for different levels of this condition, i.e., for different scene depths. For a more in-depth description of this variation, as well as further discussion, we refer the reader to [6].

Applications

We implement three proof-of-concept applications of our translation gain detection thresholds both to validate our thresholds, and to show that they can be useful for alleviating different important problems in VR for which no definitive solution exists. The first one brings an improvement in terms of visual quality to 6-DoF viewing systems. Adding 6-DoF to captured 360º content usually incurs in artifacts in the resulting content, which are more evident as the user displaces [7]. We propose to apply our compression method (virtual camera translates less than the real user) to reduce the visibility of the artifacts, by unnoticeably reducing users' virtual translations. A second application shows how we can help overcome physical constraints during VR viewing: We propose to use our expansion method (virtual camera translates more than the real user), so that the same virtual task can be completed within a smaller physical space. Finally, a simple, proof-of-concept application proves how our compression thresholds can be used to reduce motion sickness by reducing compound movements between a pre-established camera trajectory and users' head translations. All three applications are validated by means of additional user studies. All of them are shown to improve when our method is applied, with our manipulation technique remaining undetected.

Conclusions

We have presented the first attempt at measuring detection thresholds for lateral translation gains for head motion during natural VR viewing. Our psychophysical experiments reveal that significant compression and expansion of the virtual camera motion is possible, while remaining imperceptible to users. We have also found an important dependency with the depth layout of the elements in the scene. We have demonstrated that our thresholds are robust, and can be used to address several open problems in VR: improving 6-DoF viewing, overcoming physical constraints, and reducing motion sickness.

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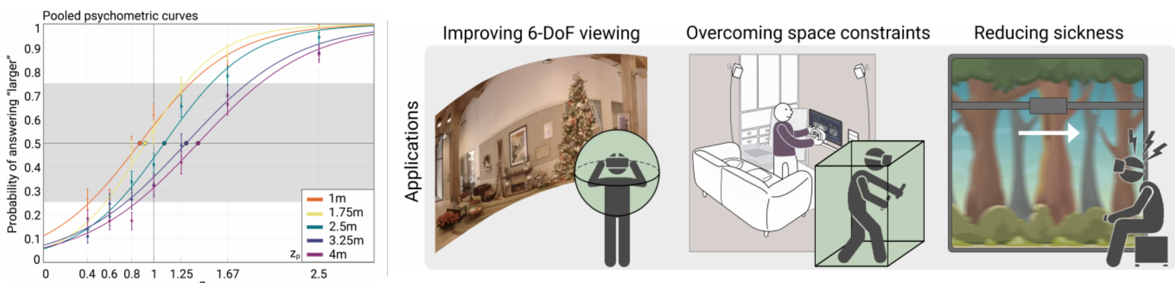

Figure 1. Left: Psychometric curves from our psychophysical experiment. The grey area represents the translation gain that can be unnoticeably applied. Right: Overview of the three proposed application to validate our thresholds.