FLOATING CITIES FOR CLIMATE CHANGE ADAPTATION: EXPLORING MOTION PERCEPTION THRESHOLDS VIA IMMERSIVE VIRTUAL REALITY

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INTRODUCTION

Sea level rise due to climate change is predicted to consume 1.79 million km^2 of land alongside the displacement of 187 million people by the 22nd century (Bamber et al. 2019). In response, both the United Nations Human Settlements Program (UN-Habitat) and the American Society of Civil Engineers (ASCE) have advocated for the development of floating cities as a sustainable solution towards climate resilience and adaptation. However, large-scale floating structures for permanent human habitation have not advanced beyond architectural speculation with no guidelines to inform their design. Unlike traditional land-based buildings, no attempts have been made to investigate their habitability (i.e., human comfort) under low-frequency oscillations induced by wind and waves. This work employs immersive virtual reality (VR) to ascertain motion perception thresholds across all six degrees of freedom (DOF) for a hypothetical floating structure situated in Auckland, New Zealand. Through this process, we aim to establish VR as an invaluable tool for the exploration of immersive visual stimuli to motion perception and comfort criteria within complex floating environments.

MOTION PERCEPTION AND VIRTUAL REALITY

The popularization of supertall skyscrapers since the mid-20th century has necessitated the exploration of perception thresholds to building oscillations induced by wind. Since the 1970s, significant research have been devoted towards the quantification of horizontal (surge and sway) acceleration magnitudes at which vibrations become perceptible to occupants placed within sealed vibration chambers (Tamura et al. 2006). Despite its physical realism, this approach ignores the contribution of external visual stimuli to motion perception in addition to neglecting vertical (heave) and rotational (roll, pitch, and yaw) components which are expected to manifest for floating structures excited by waves.

By enabling human-computer interactions at full scale, immersive VR serves as an indispensable tool for the simulation of building environments that are too difficult to replicate in the real world (Wang et al. 2023). The application of VR via a head-mounted display (HMD) has also been demonstrated to induce sensations of self-motion, despite the absence of any physical movement (Harris et al. 2000). As such, VR has been widely used to study human responses to motion within both realistic and artificial settings (Riecke et al. 2006). However, past studies have largely focused on rapid movements akin to being in a moving vehicle. The use of VR for the replication of low-frequency environmental vibrations in the context of floating structures has not been explored.

ENVIRONMENT DESCRIPTION

The floating structure adopted in this study was based on a prototype proposed by Wang et al. (2019). The structure consists of six 30 m tall buildings symmetrically distributed on a pontoon 100 x 75 m in size. In this study, the floating structure was placed in Waitematā Harbor facing a 1:1 (real-scale) model depicting the central business district of Auckland, New Zealand (see Figure 1). The interior environment consisted of an apartment unit with a large window facing the Auckland skyline as seen in Figure 1. The unit was located approximately 30 m above sea level to reflect its position at the top of the building. Rendering of the internal and external virtual environment was carried out via the Unity3D game engine which also included realistic sky and sea effects.

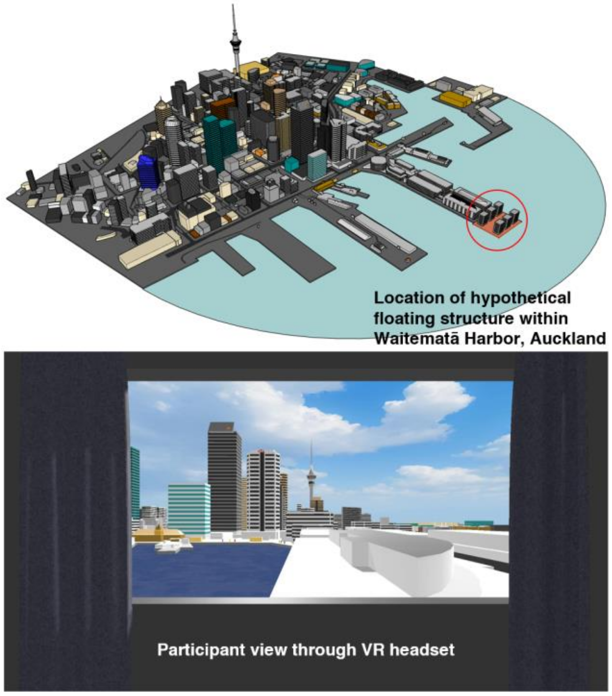

Figure 1 – VR simulation of a floating building situated in Waitematā Harbor (Auckland, New Zealand) used as a benchmark for motion perception studies

MOTION PERCEPTION STUDY

Participants were recruited from the student and faculty population at the University of Colorado Denver. Subjects were instructed to remain seated while observing the virtual environment though the HTC VIVE Pro 2 HMD supporting a total display resolution of 4896 x 2448 pixels at an average refresh rate of 90 Hz. Pixel matching analyses confirmed that this resolution is sufficiently high to induce visual movement even at the lowest motion amplitudes considered in this study.

Once the participant has been familiarized with the VR environment, sinusoidal motion with a frequency of 0.1 Hz (typical excitation frequency for ocean waves and building vibrations in general) associated with one of the six DOFs (selected randomly) will commence. The motion signal begins from zero then gradually ramps to a maximum acceleration of 0.30 ms^{-2} and 0.010 $rads^{-2}$ for translational (surge, sway, and heave) and rotational (roll, pitch, and yaw) components, respectively (Figure 2). This ramping occurs over a total of 20 acceleration increments with each increment lasting 30 seconds. Note that the signal profile is similar to that adopted for physical vibration chambers used to study wind-induced vestibular perception thresholds (Tamura et al. 2006).

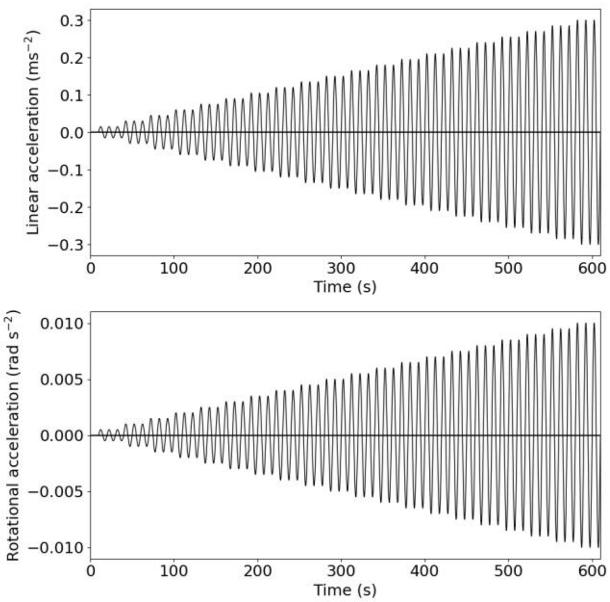

Figure 2 – Acceleration profile for translational (surge, sway, and heave) and rotational (roll, pitch, and yaw) components

Participants were given a controller and asked to press a button once they perceive that the room they are in is experiencing motion relative to the stationary view outside the window. The corresponding acceleration magnitude was then recorded and designated as the perception threshold for that particular DOF. Sinusoidal motion will then commence for the next randomly selected DOF to which the participant will be asked to indicate their perception threshold. The experiment will terminate once perception thresholds across all six DOFs have been identified.

RESULTS

Preliminary trials indicate strong correlations between the direction of translational/rotational motion and its associated visual sensitivity. For translational DOFs, motions along the surge direction (back and forth towards the city) were generally the most difficult to detect while heave oscillations were the most perceptible. For rotational DOFs, roll motions exhibited higher perception thresholds (more difficult to detect) than pitch or yaw. Future studies will expand the trials to include a larger population while also exploring the influence of oscillation frequency on motion perception within floating environments. This work ultimately demonstrates an innovative use of immersive VR to assess human comfort and decision-making pertaining to the development of floating infrastructure for climate change adaptation.

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